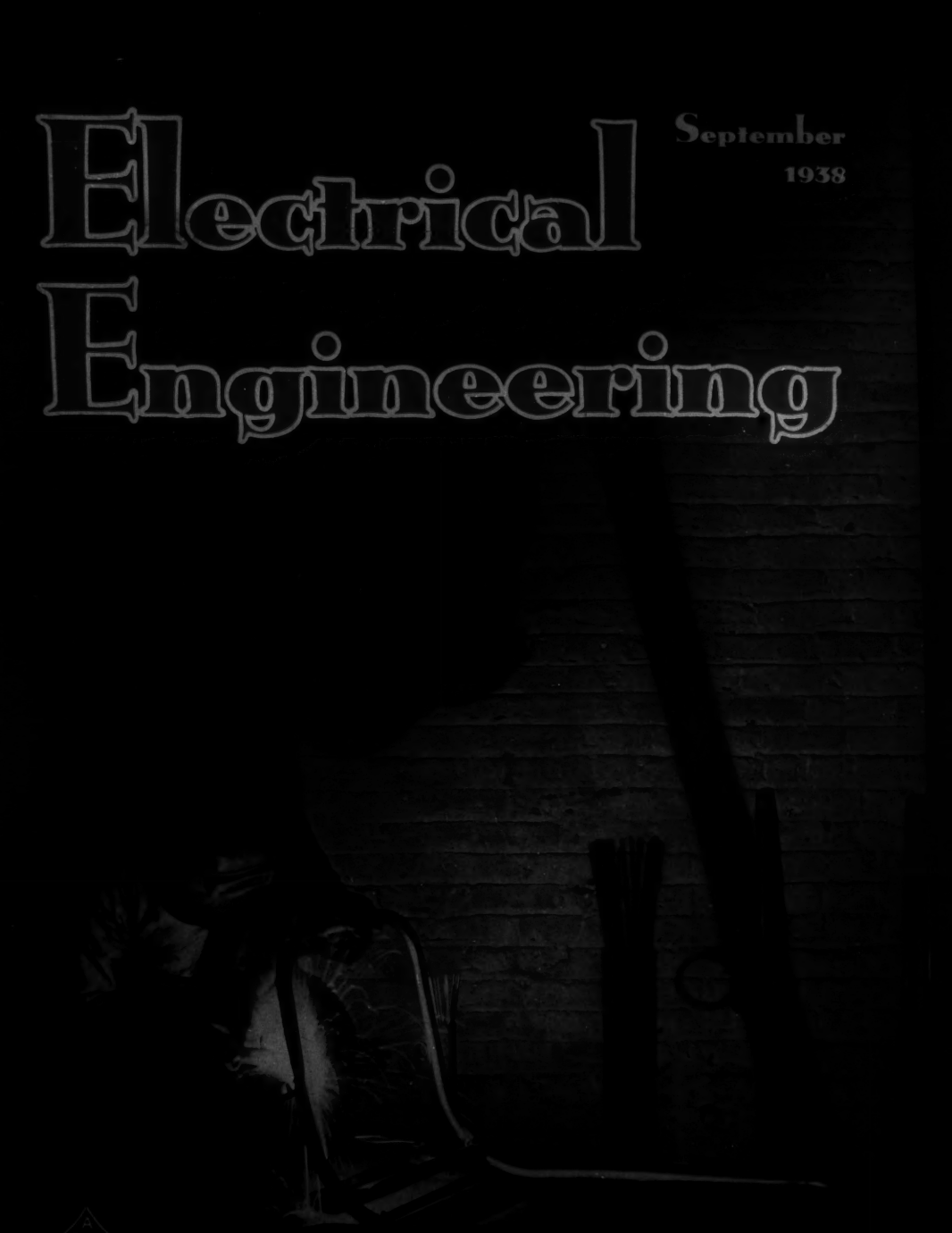
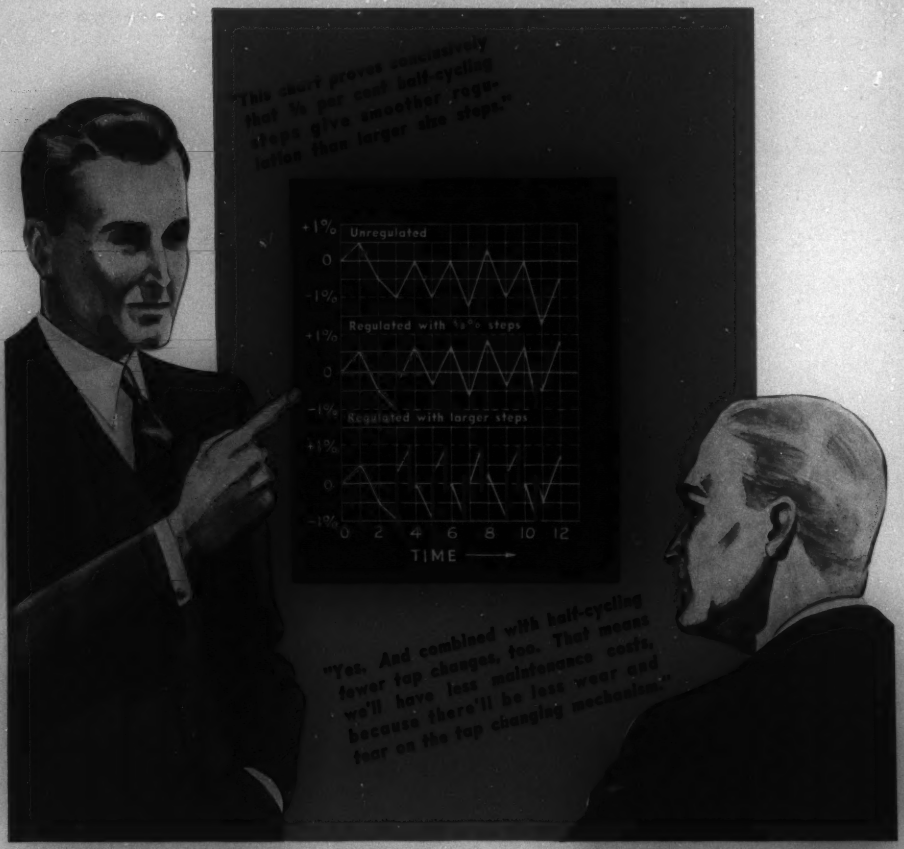
Electrical Engineering

September
1938



Published Monthly by the
American Institute of Electrical Engineers


"This chart proves conclusively that ½ per cent half-cycling steps give smoother regulation than larger size steps."
+1%
0
-1%
Unregulated
Regulated with ⅝% steps
Regulated with larger steps
0 2 4 6 8 10 12
TIME
"Yes. And combined with half-cycling fewer tap changes, too. That means we'll have less maintenance costs, because there'll be less wear and tear on the tap changing mechanism."

★ Increase Your Revenue With Allis-Chalmers ⅝ Per Cent Half-Cycling Step Regulators

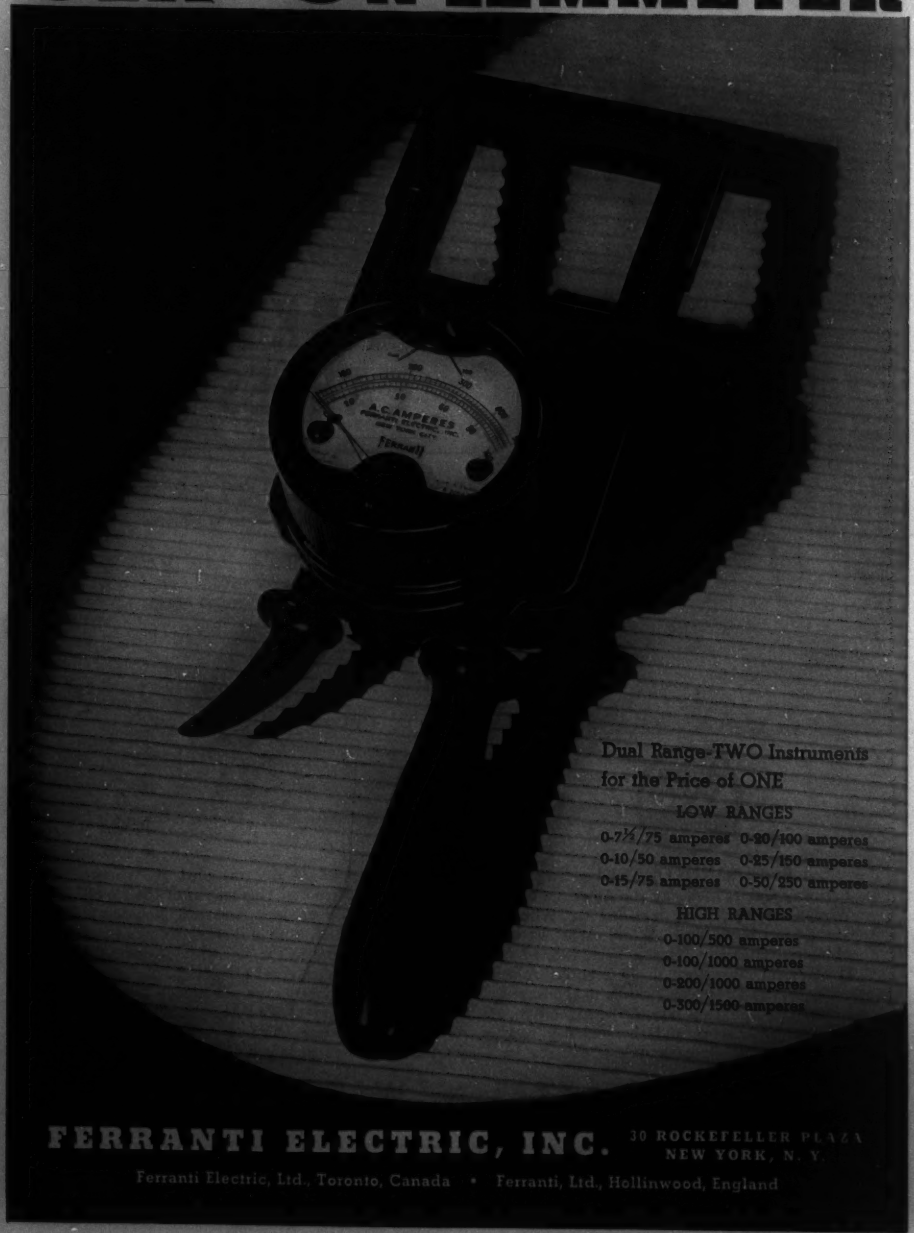
You can't afford to have unregulated voltage on your lines, because that means loss of revenue and dissatisfied customers. And yet, if you invest in a step regulator, you want the utmost in regulation at the lowest possible cost. That is why the chart these men are studying has an important bearing on your profit and cost columns. Look at it closely. You can see at a glance that regulation with ⅝ per cent steps, plus half-cycling operation, makes voltage smoother and steadier — *and does it with only two tap changes and two switching operations.*

Compare that record with that shown by the curve for larger size steps and full cycling. Voltage not as smooth, and, what's more, nine tap changes and eighteen switching operations in the same length of time. What does this mean to you? Just this: With ⅝ per cent steps and half-cycling you get closer regulation with fewer tap changes, and that means less contact deterioration and less maintenance costs. Many step regulators have appeared on the market since Allis-Chalmers first introduced the step regulator. But remember—Allis-Chalmers is still the only company that builds your step regulator with ⅝ per cent steps and half-cycling operation as standard equipment. And that means that only with the AFR (for station installation) and the DFR (for distribution systems) can you obtain the maximum in regulation at the minimum in costs. Choose the AFR or DFR units and discover for yourself how quickly they pay for themselves by increasing your revenue.

071

TRANSFORMER DIVISION
ALLIS-CHALMERS
MILWAUKEE · WISCONSIN

CLIP-ON AMMETER



Dual Range-TWO Instruments for the Price of ONE

LOW RANGES

0-7½/75 amperes 0-20/100 amperes
0-10/50 amperes 0-25/150 amperes
0-15/75 amperes 0-50/250 amperes

HIGH RANGES

0-100/500 amperes
0-100/1000 amperes
0-200/1000 amperes
0-300/1500 amperes

FERRANTI ELECTRIC, INC. 30 ROCKEFELLER PLAZA NEW YORK, N. Y.

Ferranti Electric, Ltd., Toronto, Canada • Ferranti, Ltd., Hollinwood, England

Light AND Power
ATOP WHITEFACE MOUNTAIN
...transmitted by
USS PARKWAY CABLES
WHITEFACE MOUNTAIN, New York World War Veterans Memorial Highway, near Lake Placid, New York. American Steel & Wire Company Parkway Cables will carry the power for pumps and lights at the toll house, pump house and shelter houses for years to come.

ADEQUATE WIRING SERVES AND SAVES

THOUSANDS OF FEET of Steel Taped Parkway Cables made by the American Steel & Wire Company, were installed at Whiteface Mountain, New York World War Veterans Memorial Highway. This project, located near Lake Placid, New York, in the beautiful Adirondacks, will provide scenic thrills to thousands of tourists. Whiteface is one of the highest mountains in this group, and the highway reaches to the summit almost a mile above sea level.

The Parkway Cable installed at Whiteface Mountain Memorial Highway is of the Metallic type. We also produce Amerseal Non-Metallic Parkway Cables. Both of these types are designed for direct burial in the soil without ducts, conduits, or other external protection.

Let our engineers save you money by specifying the Parkway Cable best suited to give years of faultless service. Our new catalog on Parkway Cables will be sent to you upon request.

AMERICAN STEEL & WIRE COMPANY

Cleveland, Chicago and New York

Columbia Steel Company, San Francisco, *Pacific Coast Distributors* · United States Steel Products Company, New York, *Export Distributors*

UNITED STATES STEEL

Electrical Engineering

Registered U. S. Patent Office

for September 1938—

Engineering Orientation	...John C. Parker	...369
Electrification of the Bay-Bridge Railway	...Paul Lebenbaum	...372
Tensors—in "Words of One Syllable"	...H. H. Skilling	...378
Noise Specifications for Power Transformers		...382
Our Scientific Era	...Alfred Still	...384
Abstract: Transmission Theory of Spherical Waves, 383		
News of Institute and Related Activities (See next page)		...387

Transactions Section—Papers and Correlated Discussions (Follows EE Page 402)

System Planning and Operation for Voltage Control	...T. J. Brosnan	...493
Regenerative Tension Control for Paper Winders	...H. W. Rogers	...495
Comparison of Methods of Stopping Squirrel-Cage Motors	...W. I. Bendz	...499
Capacitors for Power-Factor Correction in Industrial Plants	...C. E. H. von Sothen	...505
Multiple Lightning Strokes—II	...K. B. McEachron	...510
Photoelectric Weft-Straightener Control	...C. W. LaPierre and A. P. Mansfield	...513
Protector-Tube Application and Performance on 132-Kv Lines	...Philip Sporn and I. W. Gross	...520
Corona Voltages of Typical Transformer Insulations Under Oil	...F. J. Vogel	...531
Systematic Voltage Surveys	...R. W. Burrell and W. E. Appleton	...535
Voltage Regulation in a Rural Distribution System	...G. H. Landis	...541
Voltage-Regulating-Equipment Characteristics	...P. E. Benner and G. S. Lunge	...548
A D-C Transformer	...T. C. Lennox and E. V. DeBlieux	...554

VOLUME 57 NUMBER 9

Published Monthly by the

American Institute of Electrical Engineers

(Founded 1884)

JOHN C. PARKER, President H. H. HENLINE, National Secretary

PUBLICATION COMMITTEE—I. Melville Stein, *chairman* J. W. Barker O. W. Eshbach H. H. Henline A. G. Oehler H. S. Osborne H. S. Phelps H. H. Race D. M. Simmons M. W. Smith

—PUBLICATION STAFF—

G. Ross Henninger, Editor F. A. Norris, Business Manager
Floyd A. Lewis, Associate Editor C. A. Graef, Advertising Manager

Entered as second class matter at the Post Office, Easton, Pa., April 20, 1932, under the Act of Congress March 3, 1879. Accepted for mailing at special postage rates provided for in Section 1103, Act of October 3, 1917, authorized on August 3, 1918. ¶ Publication Office: 20th & Northampton Streets, Easton, Pa. Editorial and Advertising Offices at the headquarters of the Institute, 33 West 39th Street, New York

The Cover

Welding an airplane-chair frame electrically

Lincoln Electric Company Photo

High Lights

Voltage Regulation. Design and operation of the various parts of a power system are influenced by the permissible limits of voltage regulation, which vary for different types of load. The recent addition of new devices having low power factor and high starting current increases the importance of co-operation between manufacturers, contractors, and power companies (*Transactions pages 493–5*). A planned voltage survey may be made with both graphic and indicating instruments to determine voltage conditions in the distribution system (*Transactions pages 535–40*). Rural distribution systems have special problems because of the low load density, long distances, and need for minimum cost (*Transactions pages 541–7*). Selection of the proper type of voltage-regulating equipment to correct a given undesirable condition requires consideration of economic as well as technical factors (*Transactions pages 548–53*).

D-C Transformer. The design of devices employing mechanical commutators for transforming direct voltages involves two difficult problems: the provision of correct current collection and commutation. By using two commutators on the same shaft and connecting them to the high- and low-voltage windings of a suitable transformer, some of the usual difficulties of design may be obviated (*Transactions pages 554–8*).

Discussions. Beginning with this issue, all discussions published in the TRANSACTIONS will be correlated with their respective papers, the last remaining discussions of previously published papers having been published in the August issue. This marks the completion of the transition from the publication policy in effect during the years 1934–37 to the new plan as announced on page 1409 of the November 1937 issue of ELECTRICAL ENGINEERING.

Corona Voltages. An earlier investigation indicated that for transformer insulations under oil, electrical breakdown adjacent to square edges is a function of the stress and the distance over which this stress acted; experimental data now have been obtained that support the theory and permit its application in the practical design of transformers (*Transactions pages 531–5*).

Control for Paper Winders. In winding paper on rolls, the tension of the sheet ordinarily is controlled by a manually operated mechanism, but constant tension is extremely difficult to maintain in this manner. Tension control may be improved electrically, by means of a regenerative system of motors and generators (*Transactions pages 495–9*).

Tensor Analysis. During the last few months some readers played games with tensors, engaging in hunts and other things not entirely decorous in conventional mathematics. The unusual approach to this perfectly serious realm of mathematics now seems to be the order of the day, for in this issue an author paints a word picture, figuratively, in words of one syllable (*pages 378–82*).

New Transactions Format. Beginning in this issue, the TRANSACTIONS section will be published in a three-column format instead of the former two-column format. The new arrangement not only provides improved readability but also effects some space economy. Comments and criticisms are solicited.

Lightning Protection. For maintenance of proper protection, devices designed to protect apparatus from the effects of lightning should not include mechanical motions that take time for restoration to normal condition (*Transactions pages 510–12*).

Braking Motors. Each of the several methods of quickly stopping squirrel-cage induction motors has its advantages and disadvantages. A comparison of four of the most commonly used methods aids in the choice of the one best suited to a particular application (*Transactions pages 499–505*).

Weft-Straightener Control. A new photoelectric weft-straightener control has improved the quality of the products of weaving mills by straightening the weft threads continuously and automatically (*Transactions pages 513–19*).

Protector-Tube Application. A paper in this issue presents statistical and interpretive information on the performance of protector tubes for protecting 132-kv transmission lines against lightning (*Transactions pages 520–30*).

News 387

Portland Sets New High for Coast Convention 387
AIEE Directors Meet at Institute Headquarters 389
Plans Progressing for Southern District Meeting 390
Three Committees on Applications Combined 390
Institute Funds for Research Projects 390
Future Meetings
AIEE 389
Other Societies 391
Letters to the Editor 392
Journals for Electrical Engineers 392
The Role of the Engineering Library 392
Ambient Temperatures for Transformers 392
Personal Items 394
Membership 395
Engineering Literature 396
Officers and Committees 397
Pamphlet Copies of Papers Available 402
Industrial Notes . . . . (See advertising section)
New Products . . . . (See advertising section)
Employment Notes . . . . (See advertising section)

Electrification of Bay Bridge. The great San Francisco–Oakland Bay Bridge soon will add to the convenience of commuting across the bay for about 50,000 people, when its three electrified railway lines are placed in operation (*pages 372–7*).

Capacitors. Substantial savings in power costs may be effected by industrial customers by the use of capacitors to improve the power factor of the load (*Transactions pages 505–09*).

Our Scientific Era. A teacher of technical subjects looks at the historical aspects of scientific change and challenges the reader with some thought-provoking questions (*pages 384–6*).

Pacific Coast Convention. More than 450 members and guests registered at the recent AIEE Pacific Coast convention held in Portland, Ore. (*pages 387–9*).

Officers and Committees. Officers and committees chosen to serve the Institute during the year 1938–39 are listed in this issue (*pages 397–401*).

Coming Soon. Among special articles and technical papers now undergoing preparation for early publication are: an article on labor policy and employment, by Leo Wolman, noted economist; an article discussing the relationship that research, engineering, and education bear to social progress and welfare, by R. E. Doherty (M'27); an article emphasizing the importance of research in developing new products for industry, by Vannevar Bush (F'24); an appreciation of 1937 Lamme Medalist R. E. Doherty, by A. R. Stevenson (F'37); an article presenting test results on the influence of utensils on heat transfer from electric-range units, by W. G. Short (A'38); a paper discussing the application of a large phase-shifting transformer on an interconnected power system loop, by W. J. Lyman (A'25) and J. R. North (M'29); a paper presenting installment III of the results of a continued series of tests on oil-impregnated paper, by H. H. Race (M'31); a paper presenting the results of field testing of bushings and transformer insulation by the power-factor method, by I. W. Gross (A'12); two papers on the newly developed telephone instruments—one describing the instruments themselves, by W. C. Jones (M'29) and the other presenting the transmission characteristics of the new units, by A. H. Inglis (A'22); a paper discussing the wound core for distribution transformers, by E. D. Treanor (M'36); a paper describing a self-checking system of supervisory control, by M. E. Reagan (M'30); a paper describing a combined thyratron and tachometer speed control for small motors, by A. J. Williams, Jr. (A'27); and a paper on the protection of 22-kv substations against lightning, by E. R. Whitehead (A'30).

Statements and opinions given in articles and papers appearing in ELECTRICAL ENGINEERING are the expressions of contributors, for which the Institute assumes no responsibility. Correspondence is invited on all controversial matters. ¶ Subscriptions—$12 per year to United States, Mexico, Cuba, Porto Rico, Hawaii, Philippine Islands, Central and South America, Haiti, Spain, Spanish Colonies; $13 to Canada; $14 elsewhere. Single copy $1.50. ¶ Address changes must be received by the fifteenth of the month to be effective with the succeeding issue. Copies undelivered because of incorrect address cannot be replaced without charge. ¶ ELECTRICAL ENGINEERING is indexed annually by the Institute, weekly and monthly by *Engineering Index*, and monthly by *Industrial Arts Index*; abstracted monthly by *Science Abstracts* (London).

¶ Copyright 1938 by the American Institute of Electrical Engineers.

Number of copies this issue—20,500.

Engineering Orientation

By JOHN C. PARKER PRESIDENT AIEE

Matters important to every member of the profession were discussed by President Parker in his recent Pacific-Coast-convention address, presented here in full

FOR as long as I can remember, members of the engineering profession have been concerned about the status of their calling in the social body. This concern has not been entirely selfish. It has not been that individual discontent with compensation and with opportunity which is fairly common to all people, whether engineers or not, and which, incidentally, almost never seems to be relieved in the mind of the individual no matter how astronomical the figures that represent his income, or how Napoleonic his power.

It is true that studies have been made continuously over a long period of years having to do with the economic status of the engineer, and it is right and reasonable that such studies should be made if they can effectively be used as a guide to well-considered and fruitful conduct.

I think it is fair to say that most of the questioning, or even of the dissatisfaction, with the status of the engineer has been unselfish, both as expressed by individuals and as these inquiries have been pursued by professional groups. There have been strong differences of opinion within the profession as to the relative status of different branches of engineering both in the matter of recognition and in the matter of pay, but there has been a minimum of factional self-seeking or of indifference to the problems of other engineers in their diverse fields of activity and under widely different schemes of employment.

Whatever incidental or ultimate objectives may have been involved in the approach of engineers to a study of the status of their profession, two considerations have dominated all the discussions and all the thinking about it. First has been the query as to whether the profession has proper opportunity to render to society all the service of which engineering is capable and which the nation needs; and, second, has been the question as to whether engineering is fully understood and recognized in its professional aspects. The answer to both of these questions obviously must be "no."

No profession can ever hope to attain the absolute limit of its usefulness to society, nor is the appraisal of others ever likely to be a precisely correct one, though at some times and with reference to some professions there doubtless has been, by a part of the population, an exaggerated appraisal which may be quite as harmful in its effects as underestimate.

If we take for granted that neither can usefulness be absolute nor recognition quite precise, we approach the more practical question as to what we can do about it, and again, of course, the answer is that we will never attain completely all that we would wish. Nonetheless, by such continued questioning and by such sound means as we can practically apply, we can—we must—exert ourselves toward bringing our profession into a position more nearly representing its proper place in the social and political structure.

As a corollary, it seems almost inevitable that the economic status of the profession will, by the application of a reasonable degree of common sense and initiative, almost take care of itself. As a matter of fact, in passing, it might be noted that however greatly the individual engineer may have fallen short of full economic reward in the upper end of the scale, the profession as a whole has done pretty well for itself as compared with the other recognizably professional callings.

Among the definite efforts to establish the usefulness and the recognition of engineering there has been quite conspicuously presented to engineers the country over the matter of registration and licensing.

It is true that the Institute has been less interested in the process of registration than have engineers in other branches of the profession. This is quite what might have been expected from the very nature of our special engagement in professional work.

Whereas engineers in some other branches may, by the very nature of their engagement, find themselves—either as independent practitioners or in public employment—closely related to direct service of the public, electrical engineers more customarily have found their field in corporate employment.

The consultant and the independent designer have felt a need to protect at once the public, the profession, and themselves from the possibility that a public, unable to gauge professional attainments, might employ the services of people who, however well-meaning, could by no real standards be regarded as engineers.

Engineers in public employment similarly have felt the need to protect their calling and to protect the general public against the delegation of public engineering functions to place-holders.

There had been nothing to prevent any person who wished to do so from calling himself an engineer, and, so doing, offering his services to the unwary. Indeed neither public officials nor the general public have any adequate understanding of the niceties of technique, to say nothing of the economic and social significance, of competently engineered works.

On the other hand, in our branch of the profession, engineers generally have found direct employment in manufacturing concerns, in communication companies, the railways, great electric light and power systems of the country and other similar corporate enterprises. A smaller but appreciable number have practiced their profession as consultants or in the employ of consultants. The clients of the electrical consulting firms have, in the main, been corporate enterprises which I have just mentioned, themselves often headed by engineers, and in any event well enough advised of the seriousness of their

undertakings discriminatingly to engage competent and ethical consultants.

In the last analysis, the responsibility to the public for electrical-engineering enterprise has generally been carried by corporate organizations which either have felt their social responsibility or, if not sensitive to that, at least have recognized legal and financial liability.

I believe that this one feature of employment conditions has led our branch of the profession to be less actively interested in the processes of licensure than have conspicuously the civil engineers.

Discussion at the Institute's 1938 annual conference of officers, delegates, and members in Washington, D. C., gave almost, if not quite, unanimous expression to the belief that electrical engineers have too long delayed a recognition of the inevitability of the process of license. Perhaps we have been too self-centered to get the perspective of engineering responsibility as it affects the work of engineers in other branches. Whether we be so or not, and whether we like it or not, the process of registration and license is with us in most of the states of the Union and will extend into other states. It has not yet reached final form. What its ultimate form will be and whether there shall be a degree of uniformity among the states depends on the members of the profession themselves. Easily it may degenerate into a self-seeking mechanism actuated only by the desire for selfish gain and arbitrarily restrictive of admission to professional practice; or it may, by the exercise of broad vision and co-operative effort become an agency of public service directed, as public service is its principal objective, to the elevation of the profession.

There are certain practical aspects of our approach to a uniform license law which I would mention in passing. With too great facility the American people rush into the making of statutes. With bitter or ludicrous experiences behind us, we never seem to learn that legislation cannot progress faster than does acceptance by the vast body of decent citizens. If our license laws attempt unnecessarily to restrict the supply of competent engineers, or if too great obstacles are placed in the way of employment in junior positions of engineers not yet eligible to license, people will find their way of dispensing with engineering services or of circumventing the law.

If the junior engineer is made to feel, during his period of probation, that he has no status with the profession, he will find other and most unprofessional allegiances. I believe there is a big field of usefulness for members of our branch of the profession to offer positive and sympathetic help in avoiding such pitfalls as these.

Too much, however, must not be expected from the processes of registration and license. At best they will prove only a useful implement for marking a minimum level. The fuller recognition of the profession and the advancement of the individual engineer must rest on lay appraisals by the general public. We cannot hope to legislate or to impose a compulsion of a reluctant public to esteem our profession nor even to increase our rate of compensation.

Other professions and, if you please, the trades have had their fling at these processes. The law and medicine have not been able to prevent ambulance chasing and fee splitting. Whatever the emoluments at the top of those two ancient professions, the rewards at the bottom end are unspeakably low, and as Doctor R. W. Sorensen pointed out in his 1938 summer-convention paper,* the average net compensation of lawyers and medical men is not as good as that of the average unlicensed engineer.

In the matter of esteem, I doubt if the average citizen thinks particularly well of lawyers, nor has the medical profession, for all its exacting processes of license, received the popular appreciation of its services which it so richly deserves.

I think I need only point to the controversies raging in the American Medical Association and to the continuous stream of articles flowing into the daily press to indicate that the medical profession today, in spite of its rigorous requirements for admission to practice, is in a most disturbed condition.

To the extent that engineering, with the other professions, has established itself economically and in social influence, the causes of success will be found much deeper. They lie in adequacy of preparation, breadth of perspective and a general professional orientation to the social body. Where professions have failed, one or another of these elements will be found to have been neglected.

These are things that cannot be legislated. They are qualities that do not belong to a profession as a whole but rather are personal and individual to the practitioners of that profession. Obviously, our profession as a profession can be competent only as individual engineers are competent. Perspective and social awareness are inherent in the individuals that make up a profession.

As with the other professions, so in engineering, the education and the processes of apprenticeship have improved rapidly. However short of the ideal we may fall, I think we have little reason, speaking in comparative terms, to question the preparation of the young engineer for the practice of his profession. Toward the attainment of a higher level, the Engineers Council for Professional Development is doing yeoman service and merits all the support that the members of the Institute can give it. Those of us who are somewhat older than the youngsters coming into the profession will do well to bear in mind that as the work of ECPD makes possible a higher level of education for engineering and more constructively developmental internships for the young engineers, our profession as a whole and we, incidentally, will benefit in public acceptance.

As to professional approach, I think engineers have little of which to be ashamed. On the contrary, I would almost hazard the claim that we have a more nearly professional attitude than the members of other professions. The intellectual integrity of the engineer is well recognized even to the extent, at times, of inducing the charge of unsympathetic inflexibility. Rarely does he become a special pleader, nor does he substitute an unctuous bedside manner for treatment of the patient.

* "The Economic Status of the Engineer," ELECTRICAL ENGINEERING, July, 1938, pages 281–5.

Engineers habitually approach their work with a sobriety and seriousness of purpose equalling that of the best practitioners of other professions. There is a detachment and a habit of factual analysis which, it seems to me, is of the very essence of the professional method.

These things the profession has done well and is on its way seriously and steadfastly toward greater performance. They are essential to the well-being of the profession and to its ability to discharge its obligations to society. To these must be added keen awareness of the rightful function of engineering in the social organism. This is the thing which, for want of a better name, one might call perspective. A broader perspective both within the profession and in an extramural sense will bring about fuller professional recognition and larger rewards. It is not enough that an electrical engineer be able never so skillfully to calculate the electric and magnetic circuits of a motor or the characteristics of a transmission line. He must, in the former case, be able through mechanical linkages to relate his motor to the operating characteristics of the driven appliance, and in the latter case must realize that his transmission circuits need structural supports, to the design of which there is essential as nice work by the civil engineer as by the circuit expert.

After we have, in sympathetic collaboration with the chemical engineer, developed magnetic materials better adapted to our communication circuits, and better processes of combustion in our boiler houses and of utilization in our furnaces, we find ourselves relating our engineering design to the processes of shop production and field construction. Our best engineering cannot be done by specialists except as these have a sympathetic and respectful appreciation of the work of other and equally important specialists.

Beyond this, of course, engineering is essentially an economic process. Be our work never so perfect technically, it is of little value to the world if it is not subjected to sound and competent balance of operating and carrying costs against benefits created.

Our duty, however, goes much further than this. As the surgeon falls short of his social duty if he regards his work as a series of "beautiful cases" while each patient regards his particular personal operation as a means to human health and happiness, so we will miss our entire objective if our job is merely technically and economically sound. We cannot ask the general public vastly to concern itself with the technical beauty of our work. Human beings are too self-centered for that sort of thing. Men will appraise our work and us as our performance expresses our keen interest in them and our desire to make ourselves of service to them.

It is a great achievement to have been able, through the ether, to transmit sound through space. It is monumental to have been able to broadcast from London or Paris to the remote farm in the New England hills or the Deep South, but it is vastly more important than that we should hear voices to be sure of what we hear.

As engineers, we take a justifiable pride in our tunnels under broad rivers, our networks of highways flung over the country, and our bridges spanning space. We must concern ourselves equally with the use to which men put these facilities. Are they the means not only for a richer commerce but for easy access of man to man in an increasingly civilized society, or shall they become only the primrose paths that lead to the everlasting bonfires? Shall our agencies of communication be the instruments of more civilized thinking or shall they be the tools of propagandists? Shall a degenerating jazz or ennobling music fill our ears and our souls? Shall our automobile roads be military highways for aggression and destruction, and the convenient means of escaping from sordid homes to blatant roadhouses, or shall they build suburban homes by providing an escape from urban congestion?

These things, as engineers, we must ponder. You say, and rightly, that we as a professional society cannot do much to determine the use that shall be made of our creations. That must be granted, but I do suggest that a proper perspective, an extension of professional thought to the social significance of what we do, will enable us as individuals to bring into the service of mankind for a higher good those qualities of honest, objective, and keenly analytic imagination which our profession possesses in a peculiar degree. We cannot do less than this. If, as individuals, to the other obligations which our high calling has laid on us, we add that of thinking and feeling in terms of the social significance of our works, we will find people not so surprised at the occasional discovery that an engineer is, after all, a human being.

If, not as engineers but as citizens, we interest ourselves more in the cultural and philanthropic activities of our communities; if doing so laymen of discriminating judgment have opportunity to discover qualities of the engineer, I am sure that the social emphasis placed on our engineering works will be changed for the fuller happiness of mankind. Perhaps too we shall learn that it is just as easy to make an engineering undertaking beautiful as it is to make it an offense to the sensibilities of nonengineers.

As we bring about, through a more active interest in the affairs of other men, a fuller realization of what engineering qualities can offer in nonengineering fields, the direction of engineering undertakings and the legislative influences surrounding them will more fully come into the hands of our profession.

The world today is in turmoil. Intolerance, impatience, and self-seeking, or even the well-meant efforts of starry-eyed idealists, easily may turn back the processes of painful human evolution.

Our profession has much to offer. That wealth cannot be placed at the disposal of mankind by a high-pressure campaign of publicity, but it can modestly and quietly be made an instrument of human betterment if individual engineers, without deserting those things which make them good engineers, will go out among the ways of men, giving to others the opportunity to discover that the great achievements which engineers have brought about in this industrial civilization of ours are not merely technical tricks and devices, nor alone the products of scientific research, but rather the result of a habit of mind and character which well can be put to use in fields far remote from technique.

Electrification of the Bay-Bridge Railway

By PAUL LEBENBAUM
MEMBER AIEE

Electrifying the railways on the great bridge across San Francisco Bay presented some unusual problems, and the completed system has many interesting features

ONE OF THE largest bridge projects ever undertaken, the $78,000,000 San Francisco–Oakland Bay Bridge now is open to vehicular traffic, and soon will be used for transporting 50,000 people to and from work every day on electric railways. At present these commuters, who live in Alameda County, across the bay from San Francisco, purchase 35,000,000 trips across San Francisco Bay each year on ferries operated by two Alameda County suburban-railway lines.

The bridge is a double-deck structure with roadways 58 feet wide, having a total length, including approaches, of 8¼ miles. The upper roadway is reserved for fast-moving vehicular traffic, the lower deck carrying a three-lane roadway for heavy trucks and an electric railway line in each direction.

As early as 1856 a bridge between San Francisco and Oakland was contemplated, but no serious intent was expressed until 1921, when private promoters petitioned the City of San Francisco for a franchise to construct such a bridge. No franchise was granted, however, and the project was deferred until President Hoover and Governor Young in 1929 appointed a special commission to investigate the economic necessity and engineering feasibility of the bridge.

In August 1930, the Hoover-Young Commission, after a thorough study, recommended the construction of the bridge, following which further developments were made in the designs and foundation surveys. In August 1932, a final report on the design and cost, as well as on traffic and income, was completed, and subsequently submitted to the Reconstruction Finance Corporation, with a request for complete financing through that body.

After a complete investigation, the project was declared by the RFC to have complied with all the requirements of a self-liquidating project, and it agreed to buy $61,400,000 worth of California Toll Bridge Authority bonds to finance the bridge, exclusive of interurban electric train service.

The financing of the interurban service was subsequently legalized by congressional act of 1934, following which the RFC earmarked about $16,000,000 of its funds for extending the rail systems of the Key System and the Interurban Electric Railway Company (Southern Pacific Company's subsidiary) from the east side of the bay into San Francisco.

The cost of the bridge railway includes the construction of a terminal building in San Francisco, its connection with the bridge proper by means of a loop, a storage yard on the present Key Mole, and the requisite rail connections with existing lines of the Key and Interurban. This part of the work will cost about $11,000,000. The other $5,000,000 will be expended for track changes in existing lines, so as to connect up with the bridge railway; for new car equipment, and for changing existing equipment to meet the requirements of operation over the bridge.

The principal and interest of the bonds issued for the railway facilities are to be met by passenger tolls, set at 2.5 cents per passenger for the first 18 months' operation, and the railways will absorb this amount during that period. Afterward, the volume of traffic handled will control the raising or lowering of the toll.

Power Requirements

How many kilowatts will it take to carry the commuters into and out of San Francisco during the morning and evening peaks; where will substations be located; what schedules and headways will be maintained; what length and weight of trains will be handled?

The Hoover-Young survey and other surveys and reports indicated that the Bridge Railway would have to be designed to carry 50,000,000 passengers annually, although the present traffic is about 35,000,000. It was on the basis of the higher figure that the operating officers of the two companies prepared the train consists (make-up of trains) and schedules. Schedules, of course, depend on speed; and speed, in turn, depends upon the ascending and descending grades. It happens that both Key and Interurban cars are geared so that their accelerating and running characteristics are approximately the same.

Maximum trains for the Key System will consist of seven new articulated units similar to those now being placed in service. Such a train is about 773 feet long, seats 868 passengers, and weighs, fully loaded, 541 tons. Each unit is equipped with four 110-horsepower motors, or a total capacity of 3,080 horsepower (5.7 horsepower per ton).

Similarly for the Interurban, the maximum train will consist of six motors and four trailers, weighing, fully

Based upon an address presented before the AIEE San Francisco Section, March 25, 1938.

PAUL LEBENBAUM is electrical engineer for the Southern Pacific Company, San Francisco. An electrical-engineering graduate of the University of California in the class of 1901, Mr. Lebenbaum started in engineering work as a tester for the General Electric Company, Schenectady, N. Y., then worked briefly on an electrification of the Northwestern Pacific Railroad before becoming associated with the Southern Pacific Company in 1903 as assistant electrical engineer. From 1909 to 1920 he was electrical engineer of the Portland (Ore.) division of the Southern Pacific Company. He returned to San Francisco in 1921 as assistant electrical engineer, and was appointed electrical engineer in 1932.

loaded with 1,160 passengers, 571 tons. Each power car is equipped with four 140-horsepower motors, or a total per train of 3,360 horsepower (5.9 horsepower per ton). The total length is 724 feet.

The Sacramento-Northern will operate one two-car train, weighing about 110 tons, in each of the two 20-minute periods during the evening peak.

The bridge engineers set 40 miles per hour as the limiting speed for trains; this to limit the impact load on the structure to a safe value. This is about the top speed of both Key and Interurban cars on the level. But there is not a foot of level track on the bridge. The 700-foot passenger-loading platforms at the San Francisco terminal are built on a 0.5 per cent grade, ascending in the direction of eastbound traffic. Leaving the terminal, the grade rises through a 20-degree curve, to a four-per-cent grade as far as Folsom Street; then a three-per-cent grade to a little beyond Tower *W*-4 at the pierhead line; then a long vertical curve, having its apex at the center anchorage, and again entering a three-per-cent descending grade just west of Tower *W*-7, the last on the West Bay crossing. From the Yerba Buena anchorage the grade rises to the center of the cantilever span over the East Channel in a series of grades varying from one per cent to 2.5 per cent. Then, after a short piece of 1.3 per cent, there is a 2.74-per-cent descending grade, practically a mile long.

Aerial photograph showing the San Francisco terminal and loop of the Bay-Bridge railway

As pointed out previously, the limiting speed on the bridge was placed at 40 miles per hour; therefore, the first thing the operating men wanted to know is the distance in which a full-length train running at that speed can be brought to a stop with an emergency brake application on both a three per cent grade and a 2.74 per cent grade. This *distance* determines the minimum headway between trains. Transposed into seconds, it was quickly found that this distance, for a train running at 40 miles per hour, was so great that not enough trains could be run during the peak periods.

Following a study of braking-time curves from speeds below 40 miles per hour, the maximum speed on descending grades for maximum carrying capacity of the tracks was set at 35 miles per hour. This will permit a headway of 63.5 seconds; however, it is expected that a 75-second headway will be sufficient to handle the volume of business offered at the opening of the

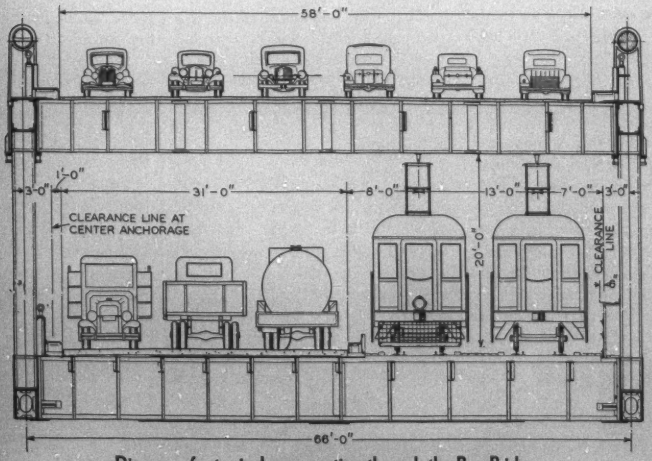


Diagram of a typical cross section through the Bay Bridge

A train typical of those to be run across the San Francisco–Oakland Bay Bridge

Bridge Railway. This 75-second headway will permit operation of 15 trains, handling approximately 9,000 passengers in the 20-minute cycle beginning at 5:00 p.m., and an approximately similar operation in the following 20-minute period. This establishes the over-all period during which the maximum half-hour power demand is likely to occur, and to which the capacity of the substation conversion machinery must conform.

A vast majority of the riders travel westward in the morning and eastward in the evening, with comparatively light travel during all other hours. This results in a low load factor because of which the consumer—in this case the railroad—is penalized by paying a high rate for the power used. Conversely, it is just during this period that the railways obtain the minimum, or commuter, fare for the service they render.

The selection of sites for substations was limited by physical conditions to San Francisco, Yerba Buena Island, and the Key Mole. The Key operates at 625 volts. It had two choices: the first to place substations at San Francisco and the Mole; and the second, to place a third substation on the Island. The use of two substations would have entailed the installation of an excessive amount of feeder copper to keep voltage drops within reasonable limits; therefore, three substations are to be built. The Interurban, operating at 1,300 volts, will have substations at San Francisco and the Mole.

Power Supply

The selection of mercury-arc rectifiers for conversion from alternating current to direct current was almost inevitable. Their ability to carry momentary current overloads of from 500 to 600 per cent and their high efficiency at the lower loads are characteristics that cannot be duplicated by rotating apparatus. This is especially true for transportation service of the character under consideration; that is, for morning and evening peak loads that are very high as compared with the average all-day load, and for high momentary swings when starting trains on the grades and curves of the bridge railway.

As finally agreed upon, the Key is to install two 2,000-kw 625-volt rectifiers in each of the San Francisco and Island substations, and two 1,000-kw units at the Mole, where it already has a 1,500-kw automatic motor generator set which is to be remodeled to operate in parallel with the rectifiers. The Interurban will install two 2,500-kw 1,300-volt rectifiers in each of the San Francisco and Mole substations. Thus each company will have 10,000 kw in rectifier capacity. The Sacramento Northern will take its energy from the 1,300-volt system of the Interurban.

The half-hour d-c peak demands based on future maximum traffic, are as follows: for the Interurban at San Francisco, 4,250 kw; and at the Mole 3,100 kw. These demands overlap, so that the demand on which payments for power are made probably will be from about 6,500 to 7,000 kw. The load factor is less than 20 per cent; therefore, the Interurban under existing rate schedules, will pay for power in kilowatts, as distinguished from energy in kilowatt-hours.

For the Key, the half-hour d-c demands are expected to be 3,300, 3,080, and 2,970 kw for the San Francisco, Island, and Mole substations, respectively.

Three-phase 60-cycle power will be supplied to the substations by the Pacific Gas and Electric Company at 12,000 volts. San Francisco substation will be fed by three cables, each consisting of three 500,000-circular-mil conductors. One of these cables originates at its station *A*; the other two in Oakland, terminating in San Francisco at the power company's station *W*. These two cables are so connected to the 12-kv bus in the railway substation that it can be fed from either side of the bay.

The Mole substation will be served at 12 kv by three feeders, each consisting of three 750,000-circular-mil conductors. These cables originate in the new switching station adjacent to the power company's station *C* in Oakland.

The Island substation of the Key System will be fed by two cables, which will be energized from an outdoor extension of the 12-kv bus in the Mole substation. All substations will be automatically operated, and remotely controlled from the Mole substation.

Switchgear

The 12-kv switchgear structure in the San Francisco substation, and also those in the Mole and Island substations, is of the metal-clad single-bus type, divided into two sections, which are connected by a bus tie breaker. Each section is connected to one incoming feeder, and the third feeder (except at the Island) can be connected to either section.

The following refers only to the San Francisco and Mole substations, although the Island substation is designed along the same general lines.

Each section of the bus feeds one 625-volt rectifier, one 1,300-volt rectifier, and one house transformer bank. The oil circuit breakers are 600-ampere three-pole single-throw, with an interrupting capacity of 500,000 kva at

rated voltage, mounted in a completely enclosed steel bus structure. They are d-c solenoid-operated at 125 volts, are trip-free, and of the lift-up type. The stationary upper circuit-breaker terminals are mounted in the switchgear housing; a built-in elevating device permits raising and lowering the breaker between the operating and disconnecting positions. When in the lower position, the breaker may be rolled out of its compartment, by means of a transfer truck, for inspection and test purposes. Suitable extension cables and connectors are provided for control purposes so that the breakers can be operated both mechanically and electrically while disconnected from the bus.

Current transformers are built directly into the switchgear structure. Potential transformers are placed above the circuit breakers, in a steel enclosure having a hinged door, the opening of which disconnects the transformers from the bus. Each switch compartment is equipped with potheads having stuffing-box connections. Switchboard-type hinged panels are mounted on the switchgear, on the side opposite to that on which the circuit breakers are located. Mounted on these panels are the necessary ammeters, relays, watt-hour meters, control switches, lamps, test blocks, and a miniature bus.

Mercury-Arc Rectifier Equipment

All rectifiers, except the 1,000-kw 625-volt units, have 12 anodes which are fed from the low-voltage windings of the main transformers, the high-voltage windings of which are delta-connected. The Key transformers have four $2^1/_2$-per-cent full capacity standard taps below 12 kv to provide for setting the transformer at the voltage that will normally be delivered to the substation. The d-c output will be 625 volts. The Interurban transformers will have a two-per-cent tap above 12 kv, and five two-per-cent taps below. This will permit Interurban to adjust its rectified voltage through the range from 1,275 to 1,350, the object being to use that voltage which will permit its cars to operate at approximately the same speeds as the Key's.

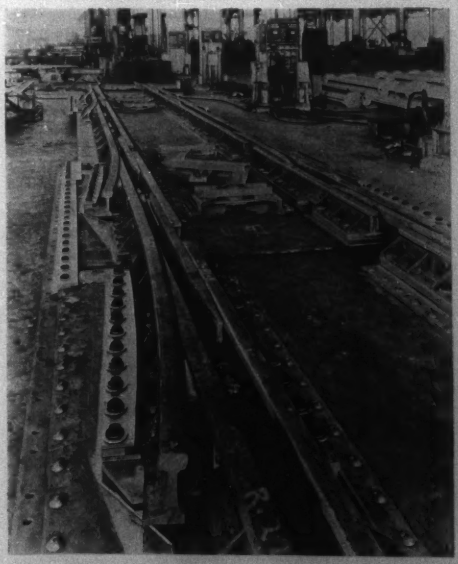
Tap-changing equipment is designed for operation under no load. For the Key it is manually operated. For the Interurban it is motor-operated by remote control, the position of the switch being given by a Selsyn indicator at the Mole substation.

The low-voltage windings are made up of four zigzag-connected wyes, providing a 12-phase supply to the anodes. The neutrals of these wyes are brought out for connection to the interphase transformer. The interphase transformer consists of three separate transformers mounted in a single tank. Two of the windings serve to connect the center points of the main transformer wyes to provide two six-phase connections. The center points of these two windings are, in turn, connected together through the third winding. A center connection to this winding provides the negative connection for the system.

The voltage characteristic of the unregulated rectifier is of the shunt type, with approximately five per cent regulation from no load to full load. The necessity for attaining maximum train speed out of San Francisco over the peak periods, made it imperative to hold constant voltage at the d-c bus up to 150 per cent of the rectifier rating. This is accomplished by the addition of grids to the anodes; they reduce the output voltage at low loads below the natural characteristic to provide constant voltage output.

The rectifier tank is cooled by a system in which the treated cooling water is continuously recirculated through the rectifier. The amount of water is regulated by a thermostatically controlled valve, and is cooled by means of a fan-cooled radiator, the motor on which is operated only when required by means of a thermal relay. The mercury-condensation pump is cooled by a similar, but smaller, cooling system.

Rectifiers are put on and taken off the line by supervisory control. When the supervisory relay gives the indication, and when the three-phase voltage of the proper value is available, the automatic control equipment is allowed to function. When the tank temperature is within predetermined limits and when the pressure in the tank is sufficiently low, the master control contactor closes, the exciting arc is established and is maintained until the rectifier is shut down. The oil circuit breaker is then closed, applying voltage to the main anodes, after which the d-c circuit breaker connects the rectifier to the d-c bus.



Photograph showing method of compensating for thermal expansion in both running and guard rails. The link and coupling arrangement between the two running rails is for equalizing the total bridge movement between the sliding joints

Most recent architect's drawing of the San Francisco–Oakland Bay Bridge railway terminal being erected in San Francisco

Each unit is also provided with automatic devices designed to protect at all times against the following abnormal conditions:

1. Low or single-phase a-c supply voltage.
2. Severe a-c overcurrent.
3. Arcback.
4. Succession of arcbacks, in which case rectifier is shut down and locked out.
5. Transformer overtemperature.
6. Too high or too low rectifier tank temperature.
7. Too high rectifier tank pressure.
8. Failure of cooling water to the mercury condensation pump.
9. Too high blower, vacuum or water pump motor temperature.
10. Failure of rectifier to be connected to a-c or d-c system within a predetermined time, in which case rectifier is shut down and locked out.

Studies made by the engineers of the manufacturers, indicated that no interference with communication circuits would result from the harmonics in the rectifier output voltage and current. The principal reason for the absence of interference is that all of the communication conductors in the area that might be affected are located in underground duct lines. These studies also indicated that there was little likelihood of interference on the supply side, as both the power and telephone cables are in underground ducts.

D-C Switchgear

All circuit breakers for 1,300-volt service are high-speed, bucking-bar type, mounted in removable trucks, which, when in place, form a portion of a completely metal enclosed bus structure. Each truck carries with it a steel instrument panel on which are mounted the ammeter and protective and functional relays where required. A truck cannot be removed with the breaker in the operative position. A set of finger contacts mounted on porcelain supports on the removable truck engage with a set of blade contacts similarly mounted in the stationary structure. These latter are connected to the 4,500-ampere main bus. When they are pulled out, the circuit breaker may be operated while being tested and inspected.

In each station the 1,300-volt rectifiers are connected to the bus by 3,000-ampere solenoid-operated breakers, equipped with holding coils and magnetic blowouts. They operate automatically when the rectifier is started or stopped, and clear the machine in event of reverse flow of current.

The feeder breakers are also solenoid-operated, but in addition, are equipped with devices that open the breakers on short-circuit-current values which are less than the overload settings of the breaker. They are equipped with the necessary resistors, contacts, and relays for automatic reclosing with the use of feel-out resistors, provided that load conditions on the feeder are within set limits.

Supervisory Control

The supervisory-control apparatus to be used for remote control of the San Francisco and Island substations is known as the Visicode type, using standard telephone relays, and requires two line wires between the dispatching office in the Mole station and the Island, and two between the Mole and San Francisco. Telemetering facilities will be provided so that the dispatcher in the Mole substation may have a knowledge of conditions at the other substations.

At the Mole the rectifiers will be started and stopped by push buttons, and by the supervisory control at the other two substations. The operator at the Mole will start and stop the machines by closing or opening the 12-kv a-c circuit breakers, whereupon the machines will connect themselves automatically to the a-c and d-c buses. Both supervisory control and telemetering are carried on over the same pair of wires to each substation.

For the San Francisco substation there will be a total of 35 supervisory operations. Similarly, for the 625-volt Island substation, a total of 20 supervisory operations is being provided.

In addition to the supervisory relay equipment, interposing relays are located at the remotely controlled stations. They relay the control of operations from the supervisory relay equipments to the power-control circuits of the circuit breakers and other apparatus remotely controlled. They close the same circuits ordinarily closed by hand-operated control switches in manually-operated substations.

House Transformer Banks

Connected to the 12-kv bus in each substation by oil circuit breakers in all respects similar to those for the main transformers are two three-phase banks of transformers supplying 240/120 volts for lighting and 240-volts for battery-charging sets, motors on the rectifier heat exchangers and vacuum pumps, and for the auxili-

aries that actuate the voltage-regulating control grids of the rectifier anodes.

At the San Francisco substation, each of the two 12-kv house-bank breakers is used also to control a three-phase circuit that will supply the San Francisco terminal station with power and light. Two three-conductor rubber-insulated metal-armored self-supporting cables will be run overhead on the catenary bridges; the cable supports are special castings, designed to fit the curvature of the cables at the point of support. One of the provisions of the power schedule for electric railways permits this incidental use of energy for facilities directly associated with the operation of the railway; it will result in a substantial reduction in the cost of light and power at the terminal from the cost if energy had been supplied under commercial rate schedules.

At the Mole substation a three-phase open-wire circuit will be connected to the load side of one of the 12-kv house-bank breakers. It will supply energy for lights and motors in the car-equipment-inspection buildings of the Key and Interurban at the east end of the storage yard.

Contact System

The bridge railroad will consist of 32 miles of electrified tracks, divided into approximately 20 miles of main-line tracks and 12 miles of set-out and storage tracks. The latter are on the Key Mole, the set-out tracks being used for making up or setting out trains, or sections thereof for the peak periods, and the storage tracks being used for the storage and inspection of cars and trains at other than peak periods.

The overhead, or 1,300-volt, contact system, for the 14 miles of main line tracks will be what is known as compound catenary, which consists of a main messenger, an intermediate messenger, and two contact wires. In order to insure that trouble on the overhead on one track would not affect operation over the other, the two are maintained as entirely separate feeder systems between the San Francisco substation and the East End tie station, which is the point (at or near 26th Street in Oakland) where they join the existing Interurban contact system, with these exceptions: at the San Francisco substation, at the Yerba Buena Island tie station, at the Mole substation, and at the East End tie station, the contact system in each track is sectionalized, and each side is connected separately to a common bus through a high-speed circuit breaker, which to that extent permits paralleling of the eastbound and westbound trolleys.

It was known, of course, that each of the two tracks which form a common return for both 1,300-volt and 625-volt propulsion currents would consist of two 90-pound running rails and two 90-pound guard rails having a conductivity equal to about 3,500,000 circular mils of copper.

An analysis of the train diagram and the load curve enabled the engineers to determine the traffic condition that would create the maximum voltage drop, which had been limited by agreement to 75 volts for the 625-volt system and approximately 155 volts for the 1,300-volt system. The copper cross section required for the positive side of the circuit was about 1,000,000 circular mils. This was disposed of in the compound catenary as follows: The main messenger is a 500,000 circular-mil 37-strand hard-drawn-copper cable; the intermediate messenger is a number 4/0 19-strand hard-drawn-copper cable, and the contact wires are two number 4/0 grooved bronze of 80 per cent conductivity. The messenger is supported from the overhead structure by two $7^1/_2$-inch ball-and-socket-type suspension insulators in series, the spans varying in length from 56 feet with a four-inch sag on the bridge to spans of 240 feet with a 60-inch sag in the East Bay yard area.

The intermediate messenger is suspended from the main messenger by hangers spaced 15 feet, and the two contact wires are clipped to the intermediate alternately at $7^1/_2$-foot intervals. All fittings, suspensions, and hangers are bronze.

For 4,000 feet east from the San Francisco substation, and for 3,100 feet west from the Mole substation, a 500,000 circular-mil cable supplements the 500,000 circular-mil messenger. Its principal purpose is not so much to reduce the voltage drop as to increase the current-carrying capacity of the contact system on the heavy grades.

In the larger part of the storage yard, the contact system for the Key and the Interurban tracks will consist of a $^3/_8$-inch, 13-per-cent-bronze messenger and a 4/0 copper contact wire.

The contact systems over the storage yard tracks of both the Interurban and the Key, are isolated electrically from the main-line tracks, and are fed directly from the 1,300-volt and 625-volt busses at Mole substation, through individual circuit breakers.

On main tracks, the Key will use a 150-pound third rail for its contact system. The steel in this rail has a low carbon content, and its conductivity is equivalent to 2,730,000-circular mils of copper. The ratio of resistance of steel to that of copper is about 6.88; for running rails, with standard carbon content, this ratio is about 12. Some 55-pound third rail is used in the San Francisco terminal area, and in the Key's storage yard. The two third rails are tied together midway between San Francisco substation and the Island substation, and midway between the latter and the Mole substation, by circuit breakers of the heavy duty latched-in trip-free air-break type; they close electrically on line voltage, and trip either on overload or by remote control. For a distance of about 4,000 feet east from the San Francisco substation, the third rail is supplemented by a 1,000,000-circular-mil feeder, to decrease the voltage drop.

Cars and Equipment

When the program of rehabilitating its equipment is completed, the Key will have a total of 88 articulated units, of which 23 will be entirely new; 25 will be made up from present long and short center entrance cars, and the other 40 will have bodies reconstructed for articulation and modernized from the present vestibule type cars. Every unit is equipped with four motors and, in addition to the

(*Concluded on page 383*)

Tensors — in "Words of One Syllable"

By H. H. SKILLING
MEMBER AIEE

Tensor analysis continues to interest—and to perplex—many electrical engineers. In several previous articles and papers, including a series in the first three issues of ELECTRICAL ENGINEERING for 1938, efforts have been made to explain tensor methods and their great power and usefulness. In a hopeful effort to broaden the general understanding of the fundamentals of tensor analysis and their relation to more commonly used mathematical methods, this further discussion of the subject is published. In trying to get as close as possible to fundamentals the author of this article tells the story of tensors, figuratively, in words of one syllable, and suggests a course of study to be used as a stepping stone to a working knowledge of tensor analysis.

THIS IS a desperate adventure. It is an attempt to discuss tensor analysis without the use of any unusual notation and with no symbols other than ordinary algebraic ones. Tensor analysis is a new concept, and it is enough (for an introduction) that the idea should be new without having new notation to cloud the issue.

Of course, it is the peculiar notation that makes tensor analysis so compact, and therefore so useful. But all I hope is to give an idea of what tensor analysis is about. Then, later on, I will mention some books that will help anyone who wishes a working knowledge of the subject.

The new concept of tensor analysis is this: The electrical engineer thinking in terms of tensors thinks of all the currents in a network as a single entity. Instead of thinking, for instance, of *current in one wire*, and then of *current in another wire*, and then of *current in a third wire*, he thinks of a single idea—CURRENTS IN A POLYPHASE SYSTEM—and he uses just one symbol to express that whole idea. He writes I, and means ALL THE CURRENTS IN THE SYSTEM.

Another single idea is VOLTAGES IN A POLYPHASE SYSTEM, thinking not of several separate voltages, but of just one entity, and using just one symbol such as E. He then can write equations in terms of those symbols, although of course when the time comes to get a numerical answer it is necessary to use numerical values of the individual currents and voltages. The advantage of the tensor concept is in transformations that can be made in the symbolic form.

Tensors have been used by physicists since the end of the last century for a specific type of problem. An example is the stress-strain relationship of an elastic material. If the stress is in some direction

the strain may be in that direction also:

But in a nonisotropic substance, such as a crystal, it may be in a different direction:

As an extremely simple example consider two long springs of different stiffness arranged at right angles, as in figure 1, the distant ends being firmly fixed, but the common point being movable when force is applied. Let us now arbitrarily assume a pair of co-ordinate axes X and Y along the lines of the springs, so that when the springs are not stretched the point at which they are fastened together is at the origin.

If force is applied along the X axis, only one spring is stretched, and we find by measuring that force and displacement are proportional:

$$F_x = k_1 S_x$$

where

F_x is *force in the x direction.*
S_x is *the x component of displacement.*
k_1 is a factor of proportionality.

Then, removing that force and applying force along the Y axis, we find

$$F_y = k_2 S_y$$

with a similar meaning for F_y and S_y, and with k_2 measuring the stiffness of the vertical spring.

If a force is not along either axis, it must be divided into components, so we will say that any general force F is made up of two parts, one in the x direction, and one in the y direction:

$$F = \textit{in the x direction, } F_x + \textit{in the y direction, } F_y$$

Then, since we know the values of F_x and F_y, this can be expanded to:

$$\begin{aligned} F = {} & \textit{in the x direction, } k_1 \textit{ times the x component of } S + \\ & \textit{in the y direction, } k_2 \textit{ times the y component of } S \\ = {} & k_1 \textit{ times, in the x direction, the x component of } S + \\ & k_2 \textit{ times, in the y direction, the y component of } S \end{aligned}$$

The peculiar order of words in this statement is for a reason

Written especially for ELECTRICAL ENGINEERING, based upon an address presented before the AIEE San Francisco Section, March 11, 1938.

H. H. SKILLING is assistant professor of electrical engineering at Stanford University, Calif., from which he received the degrees of bachelor of arts (1926), engineer in electrical engineering (1927), and doctor of philosophy (1931). In 1930 he was awarded the master of science degree by Massachusetts Institute of Technology. From 1927 until 1929 Doctor Skilling was employed in the construction department of the Southern California Edison Company. Since 1929, except for a period of graduate study at MIT, he has been a member of the electrical-engineering faculty of Stanford University. He has presented several papers on power transmission before the Institute.

1. For all numbered references, see list at end of paper.

that now appears. For to be quite clear this statement requires a good deal of writing, and we will save time and trouble by introducing the following abbreviations: We will let i mean "*in the x direction*," let j mean "*in the y direction*," let $i\cdot$ mean "*the x component of*," and let $j\cdot$ mean "*the y component of*." Using these abbreviations equation for force just given becomes

$$F = k_1 i i\cdot S + k_2 j j\cdot S$$

As this is read aloud, reading in full the meanings of i and $i\cdot$ and j and $j\cdot$ it sounds just like the long equation above. Sometimes, for convenience, this is written

$$F = (k_1 i i + k_2 j j)\cdot S$$

and it means exactly the same. Then the quantity in parentheses is called a tensor. It is a sort of factor of proportionality that relates two vectors; but it is not a mere arithmetic factor, because it relates them in angle as well as magnitude. But this is a very simple and highly specialized tensor.

In the more general case of the same problem the arbitrary axes do not lie along the springs, but in some other directions, as shown in figure 2. Then as a force is applied along the X axis, displacement will not be along the X axis (we assumed springs of different stiffness) but will have both X and Y components. Experimental data take this form:

$$F_x = k_{11}S_x + k_{12}S_y$$

and

$$F_y = k_{21}S_x + k_{22}S_y$$

The total force is made up of these components, so

$$F = \textit{in the x direction, } F_x + \textit{in the y direction, } F_y$$

If the values of F_x and F_y are substituted, this becomes:

$F =$ *in the x direction,* k_{11} times *the x component of* $S +$
also *in the x direction,* k_{12} times *the y component of* $S +$
in the y direction, k_{21} times *the x component of* $S +$
also *in the y direction,* k_{22} times *the y component of* S

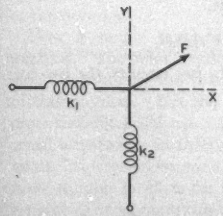


Figure 1. Two springs of unequal stiffness, to which a force is applied

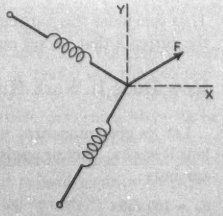


Figure 2. The same springs as in figure 1, but rotated relative to the co-ordinate axes

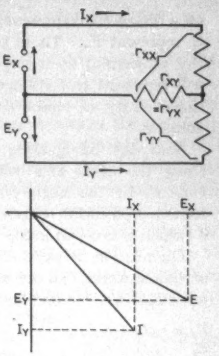


Figure 3. (Top) a network of two circuits; (bottom) the corresponding two-dimensional voltage and current tensors

Using the same abbreviations, we will know exactly what is meant when this is written as

$$F = (k_{11} i i + k_{12} i j + k_{21} j i + k_{22} j j)\cdot S$$

Again the quantity in parentheses is a tensor. Note that in the previous special case k_{12} and k_{21} were zero because a force in the x direction did not produce any displacement in the y direction, and vice versa. Again this stress-strain tensor is a kind of two-dimensional factor of proportionality.

For purposes of computation it is often useful to write a tensor in its so-called "matrix" form. The tensor just discovered is written

$$\begin{vmatrix} k_{11} & k_{12} \\ k_{21} & k_{22} \end{vmatrix}$$

and the meaning given by the i's and j's in the force equation is to be attached to the corresponding k's in the matrix merely because of the *positions* those symbols occupy in the matrix array.

A vector, such as F, is also a tensor, and the matrix is

$$\begin{vmatrix} F_x \\ F_y \end{vmatrix}$$

This force tensor is called, for obvious reasons, a tensor of rank 1, and the stress-strain tensor is of rank 2.

Now let us see how voltages, currents, and impedances in electric networks can be called tensors. To make it quite clear that the tensors and vectors in the following discussion have absolutely nothing to do with the complex quantities that are commonly miscalled "vectors" in the theory of alternating current, we will discuss *direct current* only.

Solving a Simple Problem With Tensors

There is, let us say, a simple network as in figure 3. Current in the upper circuit is I_x, and in the lower circuit I_y. Voltage applied in the upper circuit is E_x and in the lower circuit E_y. (This might represent a three-wire distribution system.) Now draw a pair of co-ordinate axes. Distances on these axes represent not force or distance, but voltage and current. Along one axis lay

off a distance to represent E_x, and on the other a distance to represent E_y. Those two values may be represented (by projection) by a single point E. This single point will represent *both* voltages. So we have the idea of a single entity (a tensor if you like) to represent plural voltages.

Next, lay off I_x along the same axis as E_x, and I_y along the other axis with E_y. Then represent both currents by the single point I. Let us now solve the following problem: Given E (which is two voltages) find I (which is two currents).

The relation between E and I is the impedance tensor of the network. To see the occasion for using a tensor, write Kirchoff's second law for the circuits:

$$E_x = r_{xx}I_x + r_{xy}I_y$$
$$E_y = r_{yx}I_x + r_{yy}I_y$$

The resistances in these equations are identified in figure 3. Of course, r_{xy} and r_{yx} are the same identical resistance. Now we may say that E, the tensor, is made up of two parts, one in the x direction and one in the y direction:

$$E = \textit{in the x direction, } E_x + \textit{in the y direction, } E_y$$

Also, it is clear from figure 3 that

$$I_x = \textit{the x component of } I$$

and

$$I_y = \textit{the y component of } I$$

Substituting these into the statements of Kirchoff's law, and the resulting values of E_x and E_y into the equation for E,

$$E = \textit{in the x direction, } r_{xx} \text{ times } \textit{the x component of } I + \textit{also in the x direction, } r_{xy} \text{ times } \textit{the y component of } I + \textit{in the y direction, } r_{yx} \text{ times } \textit{the x component of } I + \textit{also in the y direction, } r_{yy} \text{ times } \textit{the y component of } I.$$

Now this voltage-current equation is exactly similar to the stress-strain equation that appeared previously, and using the same abbreviations,

$$E = (r_{xx}ii + r_{xy}ij + r_{yx}ji + r_{yy}jj)\cdot I$$

In this way a tensor appears. Understanding that we mean this same thing, it saves writing to say

$$E = R\cdot I$$

Remember that E is two voltages, and I is two currents, and R is all of the resistances of both circuits: This is a tensor equation. (In true tensor notation certain subscripts and superscripts would be attached, but we do not need them here.)

It is quite possible for current and voltage to be alternating, and for each circuit element to be an impedance, with inductance and capacitance as well as resistance. Then

$$E = Z\cdot I = (z_{xx}ii + z_{xy}ij + z_{yx}ji + z_{yy}jj)\cdot I$$

Each current, each voltage, and all four impedances are complex quantities in such a case. Note that z_{xx} and z_{yy} are *self-* impedances, and z_{xy} and z_{yx} are *mutual* impedances.

Now, how may $E = R\cdot I$ be solved to find the currents? Formally,

$$I = \frac{1}{R}\cdot E$$

which is all right if we know what $1/R$ means. It is the reciprocal of the tensor R, and it is itself a tensor of the form

$$\frac{1}{R} = (g_{xx}ii + g_{xy}ij + g_{yx}ji + g_{yy}jj)$$

That this is correct may be proved by writing Kirchoff's law in terms of admittances instead of impedances. Call this new tensor G. Then

$$I = G\cdot E$$

Fortunately we are provided with a rule which makes it possible to compute the G tensor, if the R tensor is known. It is the rule for finding a reciprocal. It is: $g_{mn} = A_{nm}/D$, where D is the determinant

$$\begin{vmatrix} r_{xx} & r_{xy} \\ r_{yx} & r_{yy} \end{vmatrix}$$

and A_{nm} is the cofactor of r_{nm}. If you don't understand the language of this statement, never mind. The important thing is that the g's can be computed, if the r's are known.

The next question that arises is, what is the product of two tensors such as G and E? To find out, we write them out fully as

$$I = (g_{xx}ii + g_{xy}ij + g_{yx}ji + g_{yy}jj)\cdot(iE_x + jE_y)$$

and multiply, algebraically, term by term. When the product is written out, a good many of the terms contain a combination of symbols such as $i\cdot j$; since this means "*the x component of something that is entirely in the y direction*" all such terms ($i\cdot j$ and $j\cdot i$) are zero. Other terms contain $i\cdot i$, which means "*the x component of something in the x direction,*" and the combinations of symbols $i\cdot i$ and $j\cdot j$ are therefore merely unity. When these simplifications are made,

$$I = i(g_{xx}E_x + g_{xy}E_y) + j(g_{yx}E_x + g_{yy}E_y)$$

so that the two currents in the two circuits, the two components of I, are

$$I_x = g_{xx}E_x + g_{xy}E_y$$

and

$$I_y = g_{yx}E_x + g_{yy}E_y$$

That concludes this particular problem, for we have found the currents that we set out to find.

How Does It Work Numerically?

Let us give numerical values to our example and see how it works. Let us apply direct voltage in the following amounts:

$E_x = 100$ volts $\qquad E_y = -50$ volts

The negative sign of E_y merely means that it is in a direction opposite to the arrow in figure 3. Let us assume resistances:

$r_{xx} = 6$ ohms $\quad r_{yy} = 8$ ohms $\quad r_{xy} = r_{yx} = 2$ ohms

Then the matrix of the resistance tensor is

$$\begin{vmatrix} 6 & 2 \\ 2 & 8 \end{vmatrix}$$

The determinant needed to find G is

$$\begin{vmatrix} 6 & 2 \\ 2 & 8 \end{vmatrix} = 48 - 4 = 44$$

According to the rule for finding a reciprocal tensor,

$$G = \frac{1}{44} \begin{vmatrix} 8 & -2 \\ -2 & 6 \end{vmatrix}$$

The voltage in matrix form is

$$E = \begin{vmatrix} 100 \\ -50 \end{vmatrix}$$

and since $I = G \cdot E$ we have

$$I = \frac{1}{44} \begin{vmatrix} 8 & -2 \\ -2 & 6 \end{vmatrix} \cdot \begin{vmatrix} 100 \\ -50 \end{vmatrix}$$

When this is multiplied out (according to the foregoing discussion of multiplication, or by a simple general rule) the result is

$$I = \frac{1}{44} \begin{vmatrix} 800+100 \\ -200-300 \end{vmatrix} = \frac{1}{44} \begin{vmatrix} 900 \\ 500 \end{vmatrix} = \begin{vmatrix} 20.4 \\ -11.4 \end{vmatrix}$$

This tells us that $I_x = 20.4$ amperes and $I_y = -11.4$ amperes (the minus sign means that current flows against the arrow in the circuit diagram). We have found the desired numerical answer.

Now I will give you a problem to solve. To what electric network does the first simple arrangement of springs correspond? When you have found the answer you will see why a change of co-ordinate axes in a network problem is equivalent to reconnecting the elements of the network.

Now a simple problem has been solved by tensor analysis. The labor required, after the method is understood, is probably less than that for more usual solutions of this problem. But the real value of tensors is in far more difficult problems. A three-phase system with unequal impedances in the three phases and several unbalanced loads or unsymmetrical faults is an example of a more suitable problem for use of tensor methods. When a problem concerning three-phase circuits is to be solved the tensors used are in three dimensions, for there are three currents and three voltages, and the impedances and admittances are dyadics; a dyadic is a three-dimensional second-rank tensor. Sah's work deals with this kind of problem.[1,2] When there are more than three interrelated currents and voltages there must be correspondingly more than three dimensions, and this is possible mathematically although it is hard to draw on paper. Kron discusses multidimensional tensors.[4]

Building a Foundation for Tensor Analysis

I hope this discussion will not be too much criticized because it is mathematically inexact. That is admitted. It is intended merely to introduce an idea. It is not even a beginning for one who wishes to master the technique of tensor or dyadic analysis. One person who read this article in manuscript form protested that I have "used both vector analysis and matrix algebra without letting the reader know it!" If I have been successful in doing so (for I admit that I tried) it shows two things: first, that vector analysis and matrix algebra are not at all to be feared, and second, that they are absolutely essential to tensors. One or the other or, preferably, both, must be a foundation for the study of tensors.

There does not seem to be any one book perfectly adapted to the needs of the electrical engineer who wants to use tensor analysis in network problems. However, a book is promised by Sah[13] and it will be available soon. It can be studied, without preparation, by anyone with a knowledge of calculus, for the first chapters are introductory and all unusual symbols and operations are carefully defined. It is probably the best starting point for a study of the subject.

Sah refers to Gibbs-Wilson; this is the classic treatise on dyadics, but it contains much that has no immediate application and does not employ the modern developments of notation. A more satisfactory reference with the same point of view is Wills.[11] Wills is more to the point, and a great advantage is that he uses notation that carries one painlessly into a study of general tensors. Do not be misled by the fact that only the last chapter in Wills' book is entitled "Tensor Theory," for you learn quite a good deal about tensors in all the last half of the book.

These textbooks introduce the reader to tensors through the use of vectors and the physical interpretation of dimensions as space, just as in the opening pages of this article. There is no necessity for the electrical engineer to make such an interpretation, for he deals with circuits and not dimensions in space at all. So if you do not like the physical concept, but enjoy your mathematics pure, the subject may be approached through what the mathematician calls theory of groups. An excellent little book with this viewpoint is the one by Sheppard.[12] Even if you read the other books first, read this one also for the sake of the different point of view and the concise treatment.

It has been mentioned that the application of tensor analysis to electric circuit theory does not use tensors in the same sense that the physicist knows tensors, although the mathematics is the same. If you speak of tensors to a physicist he thinks of something like the stress-strain problem with springs, but applied throughout a field instead of just at a point, and extended from 2 to n dimensions. (In Einstein's general relativity, n is 4.) It merely happens that the equations of circuit theory are sets of linear equations for which the solution can be expressed in tensor notation. But the solution can also be expressed in other ways. Electrical engineers are playing with quite an assortment of mathematical tools at the

present time—tensors, sets, dyadics, matrices. These various tools are more or less similar, more or less overlapping. Take your choice.

References

The following have been published in ELECTRICAL ENGINEERING:

1. DYADIC ALGEBRA APPLIED TO 3-PHASE CIRCUITS, **A. Pen-Tung Sah.** Volume 55, August 1936, pages 876–82.

2. COMPLEX VECTORS IN 3-PHASE CIRCUITS, **A. Pen-Tung Sah.** Volume 55, December 1936, pages 1356–64.

3. THE TENSOR—A NEW ENGINEERING TOOL, **A. Boyajian.** Volume 55, August 1936, pages 856–62.

4. TENSOR ANALYSIS OF MULTIELECTRODE-TUBE CIRCUITS, **Gabriel Kron.** Volume 55, November 1936, pages 1220–42.

5. TENSOR ALGEBRA IN TRANSFORMER CIRCUITS, **L. V. Bewley.** Volume 55, November 1936, pages 1214–19.

6. Discussion of papers by Sah (page 610) and of Boyajian, Bewley, and Kron (page 614), volume 56, May 1937.

7. MATRICES IN ENGINEERING, **Louis A. Pipes.** Volume 56, September 1937, pages 1177–90.

8. WHAT IS TENSOR ANALYSIS? **Banesh Hoffmann.** Volume 57, January 1938, pages 3–9; February 1938, pages 61–6; March 1938, pages 108–09.

9. THE PROPERTIES OF THREE-PHASE SYSTEMS DEDUCED WITH THE AID OF MATRICES, **M. B. Reed.** TRANSACTIONS section, volume 56, February 1938, pages 74–7.

The following are books:

10. GIBB'S VECTOR ANALYSIS, **E. B. Wilson.** Charles Scribner's Sons, New York, 1901 (436 pages).

11. VECTOR ANALYSIS WITH AN INTRODUCTION TO TENSOR ANALYSIS, **A. P. Wills.** Prentice-Hall, Inc., New York, 1931 (285 pages).

12. FROM DETERMINANT TO TENSOR, **W. F. Sheppard.** Oxford University Press, London, 1923 (127 pages).

13. DYADIC ALGEBRA AND THREE-PHASE CIRCUITS, **A. Pen-Tung Sah.** International Textbook Company, Scranton, Pa., in press.

Noise Specifications for Power Transformers

AT A CONFERENCE on sound and vibration measurement held during the 1938 AIEE winter convention, A. P. Fugill (A'24, M'30), The Detroit Edison Company, Detroit, Mich., described a series of investigations of noise measurement conducted by that company. The company now has issued a specification describing standard methods of power-transformer noise measurement; the instructions are based upon American Standards Association tentative standards *Z*24.1 (Acoustical Terminology, 1936), *Z*24.2 (Noise Measurement, 1936), *Z*24.3 (Sound Level Meters, 1936), and the proposed AIEE Test Code for Apparatus Noise Measurement, which was issued in 1937. Transformer purchase specifications of the company now include a specification of tolerable noise level, and the company's specification is used as a basis for testing the units after delivery.

The Detroit Edison Company has used a sound-level meter for the measurement of noise from electrical equipment for more than five years. Although the investigations have included some measurement of the noise from mechanical drives, motors, fans, induction regulators, and miscellaneous equipment, most of the work has been concentrated on the measurement of noise from substation transformers, because they are most likely to be located outdoors in residential districts, where their inherent noise may be objectionable.

Altogether Detroit Edison Company engineers have measured the noise from about 175 transformers ranging in size from 100 to 6,000 kva. Both single-phase and three-phase units were included, practically all for step-down service from 24 kv to 4,800 volts. Although most of the transformers were self-cooled units, the tank size, shape, proportions, and construction varied widely; some tanks being corrugated, others being smooth with cooling surface in the form of flat tubes, round tubes, or radiators. Most of the original measurements were made outdoors where the effects of reflections from acoustical obstacles were at a minimum. The measurement of noise outdoors soon appeared to have several limitations. The noise from sources other than power transformers was difficult to control, because any accessible location was likely to be near a well-traveled highway, with consequent traffic noise. In a residential neighborhood the normal noises, such as shouting children, barking dogs, and chattering birds, often were louder than the noise from the transformer. At night crickets and other nocturnal beings frequently caused interference.

These inconveniences, and others, seemed to indicate the desirability of making noise measurements indoors, but indoor measurements involve reflections from nearby walls and other surfaces. The Detroit Edison Company wanted to make many of its measurements in a test cage located in a maintenance warehouse with plenty of headroom but limited floor space. In order to determine what effect reflecting surfaces might have on test results, the investigators arranged a series of measurements of the noise from a single-phase 500-kva self-cooled 24,000/4,800-volt transformer. Two sets of measurements were taken outdoors: one with the transformer 100 feet away from a building wall; the other with it 50 feet away. The transformer then was moved inside the warehouse, and similar measurements were taken at three positions. In the first of these positions, the transformer radiating tubes were about 11 feet from the closest obstruction in any direction. In the second position the transformer was in a corner formed by a building wall and a loading

Table I. Essential Results of a Series of Measurements of Noise From Power Transformers

Location of Transformer	Average of 20 Readings (Decibels) With Microphone: 6 Inches From Transformer 3 Feet High	6 Inches From Transformer 6 Feet High	3 Feet From Transformer 3 Feet High	3 Feet From Transformer 6 Feet High
Outdoors 100 feet from building wall	52.5	52.6	49.5	48.8
Outdoors 50 feet from building wall	53.5	51.6	49.7	49.4
Average	53.0	52.1	49.6	49.1
Indoors 11 feet from building wall	53.0	50.2	50.4	48.4
Indoors 6 feet from building wall	52.3	51.0	50.5	48.3
Indoors 2½ feet from building wall	54.3	52.0	51.0	47.9

dock three feet high. The distance from the transformer radiating tubes to the wall and to the dock was six feet, with no interference within 16 feet in the other two directions. In the third position the transformer was two and one-half feet away from a building wall on one side, the other side being clear. The essential results obtained from this series of tests are tabulated in table I. The results indicate that the difference between each set of readings indoors and the average of the two readings taken outdoors ranges from +1.3 to −1.9 decibels in a random manner. Repeated measurements under identical conditions provide somewhat better agreement, a difference of one decibel being considered satisfactory. Nevertheless, the errors seem to be relatively small, even under adverse conditions. In general a clear distance of ten feet on all sides and above the transformer is recommended.

The main difficulty in the measurement of noise is to obtain a sufficiently quiet ambient noise level. The ambient noise should be at least six decibels, and preferably ten decibels below the apparatus noise. If tests for noise are made after the regular shop working hours, little difficulty is experienced as long as the equipment noise is above 45 or perhaps 40 decibels. This will take care of all power transformers as built today.

The method by which the noise values for these specifications were obtained may be used in setting up values for any electrical equipment. The first step is to specify the voltage, load, speed, method of mounting, and such factors which affect the inherent equipment noise. Since one reading, no matter where located, is not sufficient measure of the noise from any equipment of large size, it is also necessary to determine the location of the microphone and the number of readings required to indicate properly the average noise level of the equipment.

The second step is to determine the noise level on existing equipment similar to that for which the noise is to be specified by measurement according to the code developed as indicated in a previous paragraph.

The third step is to determine which of the units measures are satisfactory for the purpose intended. This can be done only on the basis of past experience, tempered by good judgment. Care should be taken not to specify equipment much quieter than standard equipment unless there is really a need for it, because extra-quiet equipment invariably will be more expensive.

Transmission Theory of Spherical Waves

ESSENTIAL transmission properties of spherical waves are formulated in terms of familiar engineering concepts in this paper.* Such a formulation places the subject of spherical waves within bounds of transmission-line theory, thus co-ordinating two apparently distinct subjects; moreover, this plan facilitates the solution of some shielding problems and emphasizes the physical aspects of shielding. The general formulas for shielding in terms of impedances for spherical waves are derived.

Mathematically this paper is brief and limited mostly to conclusions. It contains successive sections on waves emitted by an electric current element, waves emitted by an infinitely small electric current loop, transverse magnetic spherical waves, transverse electric spherical waves, and transverse electromagnetic spherical waves.

* Abstract of 1938 AIEE summer convention paper number 38-74, by S. A. Schelkunoff (M'34), which will be published in full in TRANSACTIONS.

Electrification of the Bay-Bridge Railway

(*Continued from page 377*)

pantograph for current collection, will have four third-rail shoes that will be automatically raised or lowered by approach or exit folding ramps at the ends of the third rail territory, or where the third rail changes from one side of the track to the other.

The Interurban has 145 units of equipment, of which 85 are now motor cars, 21 are operating trailers (cars having control equipment at either end, which permits their operation at the head end of a train), and 39 are nonoperating trailers. Bridge operation makes necessary a larger proportion of motor cars to trailer cars than now prevails; first, more trains are required because of the increased mileage; and second, the ratio of motors to trailers in a train will be greater due to the heavy grades on the bridge.

Provision is being made to convert six operating and four nonoperating trailers into motor cars, the net result being 95 motors, 15 operating trailers, and 35 nonoperating trailers.

All cars are to be equipped with automatic couplers, new and higher gates on roller bearings, window stops, emergency lights, side signs designating route, and additional devices to accelerate application of the air brakes on the bridge grades and make shorter signal sections possible. Motors and trailers will be equipped further with cab signals and automatic speed control, sand boxes and sanders, and destination signs at each end of the roof.

The Sacramento-Northern is making corresponding changes in its equipments, to adapt them for bridge operation.

Signals

Each track is equipped for operation under cab signal indications in one direction only except at San Francisco terminal interlocking, where movements can be made in both directions. The cab signal indicator, which is located in front of the engineman, is equipped to give six visual illuminated signals. When leaving automatic train control tracks, equipment is provided to cut out speed control and cab signals automatically, and vice versa. In train control territory, the train cannot be operated unless the automatic speed control and cab signal system are in service.

The various cab signal lamps are lighted in response to electrical impulses impressed on the 100-cycle track circuit and picked up inductively by two receiver coils mounted on the truck about six inches above each rail.

Our Scientific Era—The Historical Point of View

By ALFRED STILL
FELLOW AIEE

Science of a few centuries ago, far from positivistic, nevertheless was dogmatic, and was based upon superstition, tradition, and mysticism. But by the end of the Middle Ages men were losing their compliant faith in tradition, and the scientist turned to material observation and experimentation for the explanation of natural phenomena. The consequent search for immutable laws again introduced in science an element of dogma, which remained effective until about the end of the 19th century. During the present era, scientific thought seems to be turning away from the realistic approach, because the shattering of seemingly well-established laws has made men doubt their own senses. The author of this article stands in the middle of this era, looks at science in retrospect and in prospect, advances some provocative riddles, but lets the reader contrive to find his own answers.

THERE is a growing belief that the modern physicist has been forging ahead too fast; or, in vulgar parlance, that "he has bitten off more than he can chew." If this belief existed only in the minds of those who cannot understand the bewildering and ever-changing theories which encourage the scientist in his endless investigations, it would not be disturbing. But there are many indications that the scientist himself—especially the mathematical physicist—is beginning to wonder whither he is drifting, and why the phenomena of nature do not adapt themselves more perfectly to the particular scheme of things which happens to be nearest to his heart's desire. This is discouraging for Youth whose landmarks are no longer stationary and whose aspirations are less exalted than when he relied, with unlimited confidence, upon the authority of his teachers.

The method of science is cumulative. We discover what were formerly thought to be unalterable truths, and we invent what we call laws of nature. Then we try to define them. For this purpose we use either the symbols of the mathematician, which is the easier way; or, if we are exceptionally clever, we use words. This pleases the layman because he thinks he will at last be able to understand what the scientist has to tell him. But he deceives himself. He has either forgotten, or else he never knew, that words also are symbols, differing in form, but not in essence, from the Greek letters and the funny curls and pothooks with which the mathematician masks his deeper thoughts. The scientist makes a record of his findings, thus adding continually to our store of admitted facts, and providing material for the writers of history. The reader of such history will learn how almost countless hypotheses have been created, cherished by their zealous exponents, and discredited by the inventors of new hypotheses. The latest theory is often the most pleasing, and as such is helpful for the time being in stimulating the scientist to further efforts. But there is no finality; nothing but an addition to our rather cumbersome store of scientific data, and a change in our appreciation of the world we live in. The scientist and the student of science are in the stream, and perhaps of it; but they have not "arrived"; there is, indeed, no conclusive evidence that they are arriving; merely a continual change in scenery, with things of stirring interest happening all the time.

Yet it is for these reasons—for there seem to be no others—that an optimistic, if not very thoughtful, minority has believed that the progress of society along scientific lines must ultimately lead to a better, or less imperfect, civilization.

Many of the older theories appear to us now, in the light of our riper knowledge, as very weak, unsatisfying, and even foolish. What adequate reason, derived from history, can possibly be advanced in support of the view that our present imposing scaffolding of mathematical symbols based on *numbers* will support us any more firmly than the crumbling theories of the past, based on the logic and common sense of their period?

The philosophers of our age have almost succeeded in convincing the physicist that no theory, however attractive, which he may have to offer, will ever shatter the screen of *appearance* and bring us face to face with *reality*. There are those who believe that such views are discouraging and should not be tolerated. Why? They cannot tell us; and since they are also quite incapable of defining the thing which they call reality, there is surely no occasion to weep over the milk of nebulous perfection which has never been spilled.

It is indeed doubtful that the attainment of perfection and the discovery of a world of reality would satisfy our longings or appease our restless souls. The idea of finality is distasteful to many, and science itself, which is a creation of man's intellect, is merely a process by which nature may be studied. It makes no promise of an ultimate complete understanding of nature, neither is there anything to suggest that what is discovered by applying its method is true. The scientist is beginning to understand this, and usually expects no other reward than the contentment, if not the joy, which he experiences in the pursuit of knowledge.

Written especially for ELECTRICAL ENGINEERING.

ALFRED STILL, a native of Inchbrook, England, was educated at the Collège de Dieppe (France) and Finsbury College (England) before becoming associated with the consulting engineering firm of Fawcus and Cowan, Chester, England, in 1889. In 1891 he became chief designer for the Manchester Edison and Swan Company, where he remained eight years. From 1899 until 1911 he was chief engineer and managing director of Cowans, Limited. In the latter year he went to Canada to become chief electrical engineer to the Lake Superior Corporation, Sault Ste. Marie, Ont. Two years later he was appointed to the electrical-engineering faculty of Purdue University, where he remained in charge of the courses in electrical design until his retirement in 1934. He has contributed freely to the technical press in the United States and England, and is the author of several widely used textbooks on electrical engineering.

About one hundred years ago, soon after the discoveries of Michael Faraday were bearing fruit and pointing a new way for the advance of civilization, a period had been reached when the scientist was in the ascendant. He had already been acclaimed by the populace as its new guide and saviour. In physics especially—"the science of the nature of things"—rapid progress was being made. Men were losing faith in tradition and the lingering shibboleths of an effete medievalism. They had begun to realize that the effrontery of their religious leaders had been assumed without justification and was entirely unwarranted; they clamored for something new to worship. They asked the physicist what he proposed to do about it. He gave them the engineer.

And so it was that materialism became rampant. The world of science, which has always been the world of appearance, became also the world of reality. For tired intellects, there is nothing easier than to suppose that whatever seems to be, actually is. The materialistic conception of the universe was convenient to the scientist of the 19th century, and as a philosophy it was welcomed by the people. It was a mode of thought which strengthened the growing tendency to regard the engineer's application of science to practical purposes as the supreme contribution of the physicist. Pure science might interest the highbrows; but applied science was the meat of the people. It gave them not only power over nature, but also an improved technique in the subjugation of their more stupid brothers. In the belief that they wanted power more than anything else, they looked forward with a childlike eagerness to a scientific millenium.

The scientists of the Victorian period were almost as fatuous as their followers. They had difficulty in realizing that the process of observation and accurate measurement which so admirably fulfilled their expectations was, if not an end in itself, little more than a tool in the hands of experts who, if they were wise, might use it to the advantage of mankind, and if they were foolish, could put it into the hands of intellectual inferiors to be used or abused according to their whim. Writing in 1931, Bertrand Russell said (*The Scientific Outlook*, W. W. Norton and Company, Inc.; page 268): "The new powers that science has given to man can only be wielded safely by those who, whether through the study of history or through their own experience of life, have acquired some reverence for human feelings and some tenderness toward the emotions that give colour to the daily existence of men and women." What, then, are we to conclude? Surely not that these recently acquired powers *are* being wielded safely. But we can always close our eyes to the obvious, and drift. This is, indeed, the conventional thing to do. We may be piling up a stack of troubles for future generations, but we will not have to rehandle them. "Take therefore no thought for the morrow; for the morrow shall take thought for the things of itself. Sufficient unto the day is the evil thereof."

The scientists of the 19th century sought laws that they assumed to be true in a world that they believed to be real. By their attitude of mind, they created what we call the scientific era, in which we move and have our being. But the physicist of today is no longer a materialist. His universe is not made up of lifeless material atoms obeying immutable laws in a three-dimensional space. It is something very different; but of its nature we know very little, because the physicist, who invented it, cannot tell us anything about it. What we *do* know is that he *describes* natural phenomena in terms of mathematical expressions, but no longer attempts to *explain* them. For this temperance he deserves praise; but why he should suppose—as he sometimes does—the elusive something, which he describes mathematically, to be part of ultimate reality, is a mystery which still remains unsolved.

The menial spirit of the Middle Ages had degraded science and sought natural knowledge, not by questioning Nature herself, but by rummaging among the moth-eaten manuscripts of the ancient philosophers. Such science as then existed was in the hands of necromancers, astrologers, alchemists, and physicians.

Then came the scientific awakening. Out of the medieval chaos a new world was being evolved, in which *effect* followed *cause*, and its builders were about to discover that nature is extremely simple, orderly, and sane. All this was disconcerting for the adherents of the old school of thought, and for those whose living depended upon their status quo and the continued support of whatever dogma it was their duty to disseminate. But the materialistic philosophy of the new science could not last. The triumphal progress of its exponents was too splendid and too rapid. They made the foolish mistake of accepting as their due the fulsome plaudits of the populace. They became proud and dictatorial.

The physicist of today is very different from his predecessors of a generation ago. He is not arrogant, he is not didactic, and he is at times so humble as to appear almost painfully diffident. His latest philosophy is tentative and bashful; he is annoyed with the new quantum theory which causes him much uneasiness. There are times when he seems almost abject, particularly when he fawns upon the dogmatists and wonders whether, after all, a sprinkling of superstition may not be helpful in relieving him of his heavy burden of skepticism. But in general he is honest; and this, together with his newly acquired humility renders him trustworthy and likable.

It is clear that the modern scientist is beginning to realize how very far he is from solving the riddle of the universe. He will soon be agreeing with the wise Omar Khayyam, who said: "Those who are endowed with Knowledge and with Virtue, whose profound Wisdom hath made them like Torches to their Disciples,—even these have made no Step outside this Depth of Night: they have babbled of certain Fables—and are withdrawn again to Sleep."

Let us seek a more cheerful note by determining, if possible, what the study of scientific history can do for us. In the first place, there can be little doubt that it enables us to view the present status of our particular branch of knowledge from a more rational point of view than if we knew nothing about the earlier stages of its development. The superficial study of a particular science may tend to make us bumptious and intellectually arrogant, but an understanding of the story of scientific progress should

make us humble. And although humility may not be properly appreciated in our rather blatant age, we need not be afraid of it on that account. All great scientists are, and always have been, humble. They are never ashamed to admit that much of what they have discovered they cannot understand. They mix a little philosophy with their science and, by so doing, experience less difficulty than the majority of their contemporaries in remaining completely alive until the day of their death.

Exceptionally gifted persons, including the great physicists, receive little encouragement from a democratic government. The kind of training which its votaries refer to as democratic culture is supposed to be good for the masses of the people, but it makes no pretense of being useful to genius. Democracy does not deny the fact that, in lavishing its resources upon the many, it overrides and neglects the few. When these few happen to be also the best, this policy may be considered unfortunate. Many philosophers have thought so. Plato, whose mood was sometimes ironical, said in his *Republic* that democracy is "a charming form of government, full of variety and disorder, and dispensing equality to equals and unequals alike." Modern critics of our educational system have observed that it does not encourage original thinking and is even antagonistic to genius. Whether or not this is a good feature of the system is largely a matter of opinion. Samuel Butler thought that Providence was helping us to clarify the situation. In his *Strange Notes* he says: "Among all the evidences for the existence of an overruling Providence that I can discover, I see none more convincing than the elaborate and for the most part effectual provision that has been made for the suppression of genius. The more I see of the world, the more necessary I see it to be that by far the greater part of what is written or done should be of so fleeting a character as to take itself away quickly. That is the advantage of the fact that so much of our literature is journalism.

"Schools and colleges are not intended to foster genius and bring it out. Genius is a nuisance, and it is the duty of schools and colleges to abate it by setting genius-traps in its way. They are as the artificial obstructions in a hurdle race—tests of skill and endurance, but in themselves useless. Still, so necessary is it that genius and originality should be abated that, did not academies exist, we should have had to invent them."

Some feel that Butler has overstated the case; others may pride themselves upon detecting a note of flippancy in this debatable passage, and wonder whether its author was entirely serious when he wrote it. But it is almost as difficult to believe this as to suppose that anyone with a sense of humor would have the temerity to write on so grave a subject as the education of the young.

In all seriousness, the teacher, the scientist, and even the philosopher, should heed the fact that, in this our modern age of intellectual enlightenment, Youth expects intelligent answers to the questions it may deign to put. Young people have been told that Reason now rules supreme and that questions are no longer answered by reference to Authority, whether of the living present or the unburied past. The statement is, of course, only partially true; but an attempt is being made to deal honestly with those seeking information. The concession is laudable even if somewhat premature.

We have hardly scratched the surface of the hidden mine of knowledge. The things we thought we knew have been shown to us in a different light, and we are beginning to wonder if we ever knew anything that was worth knowing. What we thought to be absolute knowledge is now seen to be a mere fiction of the imagination. We have a growing respect for the other fellow's point of view because we realize that what we thought was a "law of nature" is little else but the crystallization of our prejudices. In matters outside the sphere of politics and international relations, we are becoming gradually more tolerant.

The scientist still depends upon the evidence of his senses, but he is worried because it does not make sense. He is eager to know, but is dissatisfied with the quality of his knowledge. He feels himself drifting from the positive and complacent attitude of his predecessors, but the things he would like to cling to have no stability and no foundation.

The younger generation is fully alive to the situation. Having, on our advice and with our blessing, lost its old-time respect for authority, Youth expects little of the learned, whose attitude is a confession of their faith, namely, that nothing has ever been done rightly, or known completely, or settled finally. When Youth, in its refreshing eagerness, clamors for reliable information on this or that bewildering mystery of the universe, we of the older generation feel weak and helpless; we are not sufficiently honest to admit the appalling depth of our ignorance; but, rather shamefacedly, we tell of how such and such a thing might be so or so, while, on the other hand, it is believed by others to be this or that; and Youth is left floundering in our intellectual morass. It is in vain that the child asks his father why fire burns, or water freezes; how sunlight reaches the earth, or why rain falls to the ground. Yet these are simple and seemingly inocuous questions. Should the unsatisfied child tread closer to the forbidden borderland and suggest that the picture of his future life, as painted by his devout grandmother, may be founded upon a misconception, what then?

It is a difficult situation, but far from hopeless. The struggle must go on—it will never end. With less fear and more honesty in our hearts, we, who—by having lived longer—have surely picked up a few shreds of wisdom, would have the courage to say: "Son, do not imagine for one moment that the fields of science are exhausted; they are still chock-full of lovely secrets which you have a far better chance of discovering than we ever had. Yes, it is quite true that we know nothing; our assumed superiority was merely a pose which we foolishly enjoyed until we found it to be based upon a fallacy and no longer serviceable. But you, son, having discovered the hollowness of our pretensions, have fewer lessons to learn. We give you our world of appearance, with all its beauty that we have never analyzed, and its many riddles that we have never solved. You are young; you have a lifetime before you. We invite you to seek an answer to these riddles. It will be lots of fun!"

News

Of Institute and Related Activities

Portland Sets New High for Pacific Coast Conventions

SETTING a new all-time high mark for registration at a Pacific Coast convention, the 26th AIEE Pacific Coast convention, held August 9–12, inclusive, at the Multnomah Hotel in Portland, Ore., came to the close of its activities with a total verified registered attendance of 454. An analysis of this attendance, and a comparison with preceding conventions back through 1920, are given in the accompanying tabulations. The principal features in which this year's convention differed from those of earlier years were the selection of convention dates nearly a month earlier than those that have prevailed for several years, and the provision of a technical program having a greater than usual number of sessions and technical papers. One notable characteristic was the relatively large number of family groups that were in attendance as a part of a vacation trip. Another feature, initiated last year at Spokane and repeated this year because of its popularity, was the holding of a session on communication jointly with the Institute of Radio Engineers, who held their convention concurrently in the same hotel.

E. F. Pearson, general convention chairman

Effective in commanding attention for the opening session Tuesday morning, August 9, was the use of a bugler who sounded First Call from in front of convention headquarters on the mezzanine floor overlooking the lobby.

Mayor Carson and President Parker Speak

Presiding at the opening session was L. T. Merwin (A'10, F'33), past chairman (1916–17) of the Portland Section, who was introduced by General Convention Chairman E. F. Pearson, and who in turn introduced the Honorable Joseph K. Carson, mayor of the city of Portland. Warming to his technical audience of some 275 persons, Mayor Carson delivered a vigorous invitation and challenge to engineers to take a more prominent part in civic affairs. He said in part—"we come much nearer to having a 'perfect economy' when we do not try to make one with artificial rules—it cannot be created by government; the function of government is to protect and to encourage those leaders in business and industry who are capable of producing the things the nation needs for its existence and prosperity. We will not have sound prosperity until the scientist, the engineer, and others capable, are given rein to produce . . ."

Introducing "a bit of retrospect," Chairman Merwin recounted briefly some of the historical high lights of the Institute, nationally and locally, to show the scope and trend of development of the Institute and of the electrical industry. He outlined the growing interest that led to the organization of the Portland Section in 1909 as the 23d Section to be organized, and introduced several of the early Section chairmen including O. B. Coldwell (A'03, F'12) 1909–11, F. D. Weber (A'09, M'30) 1911–12, and Paul Lebenbaum (A'04, M'13) 1915–16, now in San Francisco, Calif.

Analysis of Attendance at 1938 Pacific Coast Convention

Classification	Portland	Dist. 9*	Dist. 8	Dist. 10	Misc.	Totals
Members	72	78	56	7	16	229
Men guests	37	18	8	1	6	70
Women guests	45	35	26	6	5	117
Enrolled students	9	15	14	—	—	38
Totals	163	146	104	14	27	454

* Outside of Portland Section territory.

Pacific Coast Convention Attendance—1920–1938

Year	Location	Attendance
1920	Portland, Oregon	251
1921	Salt Lake City, Utah	*
1922	Vancouver, B. C.	235
1923	Del Monte, Calif.	252
1924	Pasadena, Calif.	363
1925	Seattle, Wash.	408
1926	Salt Lake City, Utah	250
1927	Del Monte, Calif.	250
1928	Spokane, Wash.	250
1929	Santa Monica, Calif.	440
1930	Portland, Ore.	300
1931	Lake Tahoe, Calif.	247
1932	Vancouver, B. C.	300
1933	(No Pacific Coast Convention)	
1934	Salt Lake City, Utah	232
1935	Seattle, Wash.	269
1936	Pasadena, Calif.	*
1937	Spokane, Wash.	266
1938	Portland, Ore.	454

* Combined with summer convention.

Introduced by Chairman Merwin and received with an ovation was President Parker who spoke to the assembly on "Engineering Orientation." The entire text of the presidential address may be found elsewhere in this issue. Immediately following Doctor Parker's address, the first technical session was called to order, the opening presentation being an illustrated lecture given by A. W. Copley (A'04, F'26) of San Francisco who described the "atom smasher" research development of the Westinghouse Electric and Manufacturing Company at East Pittsburgh, Pa.

Technical Sessions

Attendance at the several sessions in Portland ranged from 275 to 45 and averaged more than 145 persons per session over the three-day period. Details of the technical program as previously published (*EE, July '38, p. 296*) were followed. Judging by the attention given, most of the papers were of absorbing interest although some were of a descriptive or reportorial character naturally not conducive to general discussion. Of the five papers presented at the communication session held jointly with the IRE, two were presented by the AIEE and three by the IRE.

President J. C. Parker speaking on "Engineering Orientation"

Presiding at the technical sessions were: F. O. McMillan of Corvallis, Ore., vice-president 1934–36; J. P. Jollyman of San Francisco, Calif., vice-president 1937–39; O. B. Coldwell of Portland, vice-president 1921–22; H. V. Carpenter of Pullman, Wash., vice-president 1930–32; C. B. Carpenter, chairman Portland Section 1938–39; L. R. Gamble of Spokane, Wash., vice-president 1937–39.

Exclusive of the student sessions, a total of 25 papers and one technical address were presented.

Student Technical Sessions

As usual, two student sessions were provided for as part of the convention program, accommodating 10 student papers:

Wednesday Afternoon—A. L. Tweeddale, Oregon State College, presiding.

Stabilized Negative Impedances, E. L. Ginzton, Stanford University.

A Thyratron Voltage Regulator for an Alternator, Ruper Sanborn, University of Idaho.

Ionization Time of Thyratrons, F. E. Llewllyn, California Institute of Technology.

Some Personalities From the 26th Pacific Coast Convention

Portland, Ore. **August 9–12, 1938**

Upper row, left to right: L. T. Merwin (A'10, F'33) chairman of the opening session and member of the general committee, president and general manager of the Northwestern Electric Company, Portland; L. R. Elder (A'10, M'26) chairman of the reception committee, sales engineer for the Portland General Electric Company; C. B. Carpenter (A'23, M'34) chairman of the publicity committee and new chairman of the Portland Section, engineer for the Pacific Telephone and Telegraph Company, Portland; Dean H. V. Carpenter (A'03, F'18) past vice-president and member of the general committee, State College of Washington, Pullman; O. B. Coldwell (A'03, F'12) chairman finance committee, also first chairman of the Portland Section (1909) and past vice-president, vice-president of the Portland Electric Power Company

Lower row, left to right: John B. Fisken (A'03, F'13) first chairman of the Spokane Section and past manager and vice-president, consulting engineer, The Washington Water Power Company, Spokane; H. H. Schoolfield (M'18) past vice-president, chief engineer for the Pacific Power and Light Company, Portland; F. O. McMillan (A'14, F'32) past vice-president, head of the electrical-engineering department of Oregon State College, Corvallis; A. W. Copley (A'04, F'26) speaker on atom smashers, also promoter for 1939 summer convention in San Francisco and a past vice-president, Pacific Coast engineering manager for the Westinghouse Electric and Manufacturing Company, San Francisco; S. E. Caldwell (A'29) chairman registration committee and past chairman Portland Section, engineer for Pacific Power and Light Company, Portland

---

Vacuum-Tube Control of Saturated Reactors as Applied to Light-Intensity Control, W. T. Harrold, University of Washington.

An Investigation of Some of the Properties of a Nonlinear Circuit, Wallace Murdock and Ray Warburton, University of Utah.

Thursday Afternoon—J. C. Beckett, Stanford University, presiding.

Oscillographic Counting of Corona Discharge, W. E. Noller and Benjamin Davis, University of California.

Electrical Aids for Individual Cases of Deafness, Joseph Mascovich, University of Santa Clara.

Volume-Limiting Amplifier for Broadcast Use, L. M. Mallach, Washington State College.

Design of an Intermediate-Frequency Amplifier, J. A. Rhoades, University of Southern California.

A Quantitative Study of Copper-Oxide Modulators, D. W. Cox, Oregon State College.

Conference on Student Activities

With Professor A. L. Taylor, retiring chairman of the committee on student activities for the Ninth District, presiding, a dinner and joint conference of Student Branch counselors and chairmen was held Tuesday evening, August 9, for the purpose of discussing problems pertaining to the operation of Student Branches in the Eighth and Ninth Districts and the western portion of the Tenth District. Of the 14 Student Branches in that territory 10 were represented by student chairmen or alternates, and 13 of the 14 student counselors were present:

Branch Chairmen or Alternates

Robert Ries, University of Idaho, Moscow.
H. R. Schneider, Montana State College, Bozeman.
A. L. Embry, University of Utah, Salt Lake City.
John Hamilton, University of Southern California, Los Angeles.
B. B. Goodridge, University of Arizona, Tucson.
E. L. Isaac, University of Nevada, Reno.
D. M. Sherwood, California Institute of Technology, Pasadena.
Jos. Mascovich, Santa Clara University, Santa Clara, Calif.
W. A. Lawrence, University of California, Berkeley.
J. C. Beckett, Stanford University, Calif.

Counselors

R. H. Hull, University of Idaho, Moscow.
W. B. Coulthard, University of British Columbia, Vancouver.
J. C. Clark, University of Arizona, Tucson.
Abe Tilles, University of California, Berkeley.
C. F. Bowman, Montana State College, Bozeman.
S. G. Palmer, University of Nevada, Reno.
W. G. Angermann, University of Southern California, Los Angeles.
F. C. Lindvall, California Institute of Technology, Pasadena.
A. L. Taylor, University of Utah, Salt Lake City.
H. F. Lickey, Washington State College, Pullman.
R. E. Lindblom, University of Washington, Seattle.
A. L. Albert, Oregon State College, Corvallis.
H. H. Skilling, Stanford University, Calif.

The total attendance of 63 also included President John C. Parker, National Secretary H. H. Henline, Chairman R. W. Sorensen of the Institute's Committee on Student Branches, Vice-President L. R. Gamble, Vice-President J. P. Jollyman, Secretary A. M. Bohnert of District 8, and others interested in Student Branch activities.

This group considered various questions of interest and importance to Student Branches on the Pacific Coast, giving considerable attention to possible ways and means of assisting students to secure employment upon graduation. Called upon for closing comment, President Parker emphasized the necessity for engineering students to prepare themselves to go out and get jobs rather than to allow themselves to be drawn into the all too prevalent current habit of depending upon "thumbing" a free ride.

Tuesday noon, August 9, a group of 30-odd national, District, and Section officers, chairmen of local membership committees, and others gathered for a luncheon and subsequent informal discussion of local questions and an exchange of ideas and suggestions. Vice-President L. R. Gamble presided. Those present included President Parker, National Secretary Henline, Vice-President J. P Jollyman, several past vice-presidents, representatives from each of the Sections of the Pacific Coast territory, and others.

T. S. Wood Wins Fisken Cup

Entertainment, sporting events, and inspection trips were carried out in accordance with the published program (*EE, July '38, p. 295–6*). A generous schedule of activities was provided for both men and women. Chief among the sporting events was the annual golf tournament, for which there were 77 entrants. Winner of the John B. Fisken Cup, principal trophy, was T. S. Wood (M'20) of Seattle—82–18, 64 net. Honors for low gross score were won (again) by J. C. Henkle (M'36) past chairman (1926–27) of Portland Section—79; runner-up was M. P. Buswell (A'37) of Seattle. First choice in the blind bogey (kicker's handicap) was won by T. H. Crosby (M'37) of Vancouver, B. C. Inasmuch as the tournament—with the exception of the Fisken Cup—was open to guests as well as to members, several guests placed themselves within the prize range. A total of some 25 valuable prizes contributed to the committee were distributed, on the basis of top man successively being given first choice; a maximum of one prize was allowed for each individual.

Committees

Credit for the conduct of the Portland convention is due to the following committee workers, and to Retiring Vice-President C. E. Rogers of Seattle through whose efforts the general committee was organized and active at a very early date:

General Convention Committee—E. F. Pearson, general chairman; D. P. Smith, vice-chairman; Corbett McLean, secretary; John Bankus, treasurer; C. C. Boozier, C. Arnott, A. M. Bohnert, R. O. Brosemer, H. V. Carpenter, A. W. Copley, L. G. Fear, W. F. Grimes, M. F. Hatch, N. B. Hinson, C. H. Hoge, J. P. Jollyman, O. L. LeFever, F. M. Lewis, C. E. Magnusson, W. S. McCrea, F. O. McMillan, H. L. Melvin, L. T. Merwin, G. W. Miller, A. S. Moody, H. S. Osborne, S. G. Palmer, E. F. Peterson, A. C. Pratt, R. W. Preston, G. E. Quinan, C. E. Rogers, M. A. Sawyer, E. F. Scattergood, H. H. Schoolfield, H. H. Skilling,

G. H. Smith, R. W. Sorensen, A. L. Taylor, A. Vilstrup, F. D. Weber, and C. A. Wolfrom.

Finance—O. B. Coldwell, chairman; L. T. Merwin, L. G. Fear, E. D. Wise, John Bankus, A. S. Moody, and G. T. Bragg.

Meetings and Papers—Walter Brenton, chairman; F. O. McMillan and C. B. Carpenter.

Registration—S. E. Caldwell, chairman; C. E. Klaus, L. A. Helgesson, C. C. Boozier, H. I. Sargent, L. L. Smith, and D. L. Brown.

Hotel—R. J. Davidson, chairman; R. W. Preston, J. D. Frantz, L. H. Andrews, O. C. Doty, W. A. Leidigh, Jr., and O. W. Hurd.

Inspection Trips—V. B. Wilfley, chairman; R. B. Barnard, W. S. Boutwell, F. M. Lewis, J. A. Hooper, L. G. Walter, W. F. Robinson, and C. F. Stevey.

Publicity—C. B. Carpenter, chairman; Berkeley Snow, A. B. Cayo, John Dierdorff, F. S. Doxey, and O. A. Demuth.

Reception—L. R. Elder, chairman; Mrs. L. R. Elder, Mr. and Mrs. O. B. Coldwell, Dean and Mrs. R. H. Dearborn, Mr. and Mrs. D. F. Smith, Mr. and Mrs. H. H. Schoolfield, Mr. and Mrs. F. D. Weber, Mr. and Mrs. V. B. Wilfley, and Mr. and Mrs. E. F. Pearson.

Entertainment—A. H. Kreul, chairman; A. O. Mangold, G. L. Walker, J. F. Spease, and H. H. Cake.

Golf—J. C. Henkle, chairman; C. C. Boozier, J. E. Yates, and W. F. Hynes.

Women's Entertainment—Mrs. J. F. Spease, chairman; Mrs. J. H. Polhemus, Mrs. F. G. Barnett, Mrs. O. L. LeFever, Mrs. L. E. Kurtichanof, Mrs. D. R. McClung, Mrs. O. C. Doty, Mrs. H. H. Schoolfield, Mrs. L. A. Morphey, Mrs. F. V. Sams, Mrs. N. V. Arntzen, Mrs. G. F. Zolling, Mrs. W. F. Hynes, Mrs. C. E. Klaus, Mrs. C. C. Boozier, Mrs. A. B. Cayo, Mrs. H. H. Cake, Mrs. C. E. Canada, Mrs. C. P. Toussieng, and Mrs. W. C. MacInnes.

Student Activities—A. L. Albert, chairman; H. H. Skilling, and A. L. Taylor.

Transportation—G. E. Bishop, chairman; E. F. Anderson, O. C. Doty, Waldo Enns, and D. E. Roddy.

AIEE Directors Meet at Institute Headquarters

The regular meeting of the board of directors of the American Institute of Electrical Engineers was held at Institute headquarters, New York, N. Y., August 2, 1938.

Present: *President*—John C. Parker, New York, N. Y. *Past Presidents*—W. H. Harrison, New York, N. Y.; A. M. MacCutcheon, Cleveland, Ohio. *Vice-Presidents*—F. C. Bolton, College Station, Texas; C. L. Dawes, Cambridge, Mass.; F. M. Farmer, New York, N. Y.; L. R. Gamble, Spokane, Wash.; I. Melville Stein, Philadelphia, Pa. *Directors*—C. R. Beardsley, C. R. Jones, H. S. Osborne, New York, N. Y.; W. B. Kouwenhoven, Baltimore, Md.; L. R. Mapes, Chicago, Ill.; K. B. McEachron, Pittsfield, Mass.; D. C. Prince, Philadelphia, Pa.; R. W. Sorensen, Pasadena, Calif. *National Treasurer*—W. I. Slichter, New York, N. Y. *National Secretary*—H. H. Henline, New York, N. Y.

Minutes of the meeting of the board of directors held June 23, 1938, were approved.

Report was presented and approved of recommendations adopted by the board of examiners at a meeting held July 21, 1938. Upon recommendation of the board of examiners, the following actions were taken: 8 applicants were transferred to the grade of Fellow; 30 applicants were transferred and 19 were elected to the grade of Member; 120 applicants were elected to the grade of Associate; 15 Students were enrolled.

The finance committee reported disbursements in July amounting to $28,672.06, and the report was approved.

Amendments to the by-laws were adopted, as follows:

Section 8 revised to read as follows, to conform with the recent amendments to the constitution limiting admission to the grade of Fellow (*EE, July '38, p. 303–04*):

Sec. 8. Transfer of an Associate to the higher grade of Member may be proposed by another member acting as sponsor, who, upon application to the national secretary, may obtain a short form upon which information may be submitted for preliminary consideration of the board of examiners, after which the sponsor will obtain the candidate's signature to the prescribed form of application, which will be acted upon in accordance with the usual procedure.

Section 43 amended, upon recommendation of the Sections committee, to read:

Sec. 43. The chairman and secretary of each Section shall be elected for the term of one year, beginning upon the date specified in the by-laws of the Section. The by-laws of the Section shall determine whether or not these officers shall be eligible for re-election.

Announcement was made of the appointment by the president of Institute committees for the administrative year beginning August 1, 1938 (list published elsewhere in this issue).

As required by the by-laws of the Edison Medal committee, the board confirmed the following appointments by the president: L. W. W. Morrow as chairman for the year beginning August 1, 1938, and J. W. Barker, N. E. Funk, and W. H. Harrison as members of the committee for the five-year term beginning August 1, 1938. The board elected from its own membership to serve as members of the committee for the term of two years beginning August 1, C. L. Dawes, A. H. Lovell, and R. W. Sorensen.

In accordance with the by-laws of the Lamme Medal committee, the board confirmed the president's appointment of E. W. Allen, A. C. Flory, and W. B. Kouwenhoven as members of that committee for the three-year term beginning August 1, 1938.

The board considered a suggestion that the activities of the technical committees on general power applications, applications to iron and steel production, and applications to mining work, would be strengthened if the three committees were combined to form a single committee, with subcommittees covering the functions of the former committees. The board authorized the consolidation of the three committees into the "committee on industrial power applications," with the understanding that the chairman of the new committee will prepare a proposed definition of scope of the committee for submission to the technical program committee and the board of directors.

Representatives of the Institute on various organizations were appointed for the one-year term beginning August 1, 1938. J. F. Fairman was appointed a representative on the Engineers' Council for Professional Development for the three-year term beginning October 1938, and L. W. Chubb was nominated for reappointment by The Engineering Foundation Board as the Institute representative on the research procedure committee of the Foundation.

Future AIEE Meetings

Southern District Meeting
Miami, Fla., November 28–30, 1938

Winter Convention
New York, N.Y., January 23–27, 1939

South West District Meeting
Houston, Texas, Spring, 1939

North Eastern District Meeting
Springfield, Mass., May 1939

Summer and Pacific Coast Convention (combined)
San Francisco, Calif., June 26–30, 1939

Middle Eastern District Meeting
Scranton, Pa., October 11–13, 1939

Great Lakes District Meeting
Minneapolis, Minn., Fall, 1939

Local honorary secretaries were appointed for the two-year term beginning August 1, 1938, as follows: V. J. F. Brain for Australia, W. Elsdon-Dew for Transvaal, Africa, and A. S. Garfield for France.

Approval was given to recommendations of the standards committee for the appointment of the following Institute representatives:

P. B. Harwood and Gordon Thompson on the Sectional Committee on Industrial Control Apparatus (to replace H. D. James and E. D. Doyle, resigned).

Professor E. D. Ayres on the Sectional Committee on Wood Poles (to replace C. D. Gray, resigned).

I. Melville Stein as an additional representative on the Sectional Committee on Electric and Magnetic Magnitudes and Units.

Professor D. F. Minor on the Sectional Committee on Wire and Sheet Metal Gauges (to replace S. H. Blake).

C. T. Sinclair on ASTM Committee *B-1*—Copper and Copper Alloy Wires for Electrical Conductors (to replace C. D. Gray, resigned).

Other matters were discussed, reference to which may be found in this or future issues of ELECTRICAL ENGINEERING.

Coffin Award to Cincinnati Gas and Electric. The Cincinnati Gas and Electric Company recently was awarded the Charles A. Coffin Medal for 1937, for its outstanding contributions to the public. The company's extraordinary efforts in maintaining uninterrupted service successfully during the Ohio River flood, and in promoting the use of electricity by effecting one of the lowest domestic rate schedules in the United States were cited at the presentation during the annual meeting of the Edison Electric Institute, Atlantic City, N. J., June 8, 1938. Accompanying the gold medal was a check for $1,000 to be given to the employees' welfare fund of the company. The Charles A. Coffin Foundation, established by the General Electric Company in 1922 in honor of its founder and first president, each year presents a gold medal and $1,000 to the company which during that year has made a distinguished contribution to the development of electric light and power for convenience of the public and benefit of the industry.

Plans Progressing for Southern District Meeting

As already announced in ELECTRICAL ENGINEERING, arrangements are being made for the AIEE Southern District meeting, which will be held in Miami, Fla., November 28–30, 1938. Headquarters will be in the Miami Biltmore Hotel at Coral Gables. Excellent facilities are available for sports—golf, tennis, swimming, and fishing—and the location of the meeting will afford attendants a few days of winter vacation.

The program will include three technical sessions and an afternoon student session. Groups of papers for the technical sessions will deal with the subjects of radio and telephony, electric power generation, and transmission and distribution. There will be other papers and discussion dealing with economic and social problems from an engineering viewpoint.

Entertainment features will consist of a smoker Monday evening and a formal dinner-dance Tuesday night. Sightseeing trips to points of interest in the Miami area will be arranged. Consideration is being given to a four-day post-convention trip to Havana via Overseas Highway to Key West, boat to Havana, and return to Miami by boat. Miami to Havana by plane will be optional at a slight increase in cost. Further information on the Havana trip will be available later after more definite plans have been developed.

Sky Line of Miami, Fla., scene of Southern District meeting

Additional Prize Awards Announced by District 8

In addition to the prize awards for technical papers already announced by the AIEE Districts (*EE July '38, p. 316*) the Institute's Pacific District (number 8) has announced the following awards for student papers for the year ending June 30, 1938:

Prize for Branch paper was awarded to Walter E. Noller and Benjamin Davis for their paper "Oscillographic Counting of Corona Discharges," presented at a joint meeting of the San Francisco Section and the University of California, Stanford University, and University of Santa Clara Branches, April 22, 1938.

Prize for graduate student paper was awarded to Robert R. Buss for his paper "The Application of Feedback to Selective and Equalizer Circuits," presented at a meeting of the Stanford University Branch, May 24, 1938.

Three Committees on Applications Combined

As announced in the report of the AIEE board of directors' meeting published elsewhere in this issue, the board has authorized the consolidation of the committees on general power applications, applications to iron and steel production, and applications to mining work into one committee to be known as the AIEE committee on industrial power applications.

It has been thought for some time that the work of these applications committees should be integrated and strengthened, and this consolidation was authorized for that purpose. Although the scope of the consolidated committee has not yet been defined, preliminary plans are to widen it to include not only the scopes of the three former committees, but other activities as well. It is planned also to have subcommittees to represent the various classes of industries in which electricity is applied extensively.

The committee on general power applications was organized in 1908; on applications to mining work, in 1912; and on applications to iron and steel production, in 1914. All three committees have functioned continuously since they were established.

J. D. Wright (A'36) assistant manager, industrial department, General Electric Company, Schenectady, N. Y., has been appointed chairman of the consolidated committee; the names of other members will be announced later.

Institute Funds for Research Projects

In the past the AIEE has sponsored various research projects by recommending to The Engineering Foundation that in the judgment of the Institute a given project was worthy of support. The Institute, however, did not provide any financial support.

This Institute activity was thoroughly discussed at the meeting of the board of directors held in October 1937, and the board approved in principle the idea of contributions by the Institute toward specific research projects that it recommends to The Engineering Foundation, but decided to limit such contributions to not more than $500 for any one project in a year and to a total sum for all such projects during a budget year not exceeding one-half of one per cent of the total gross income of the AIEE for the preceding fiscal year.

In view of this action of the board, the chairman of the committee on research, W. B. Kouwenhoven, appointed a special subcommittee consisting of W. F. Davidson, *chairman*, O. E. Buckley, and Thomas Spooner to review any research project for which sponsorship and funds are requested and to report its findings and recommendations to the committee on research and to any other technical committee interested in the given project. These committees act upon such reports and present their recommendations to the board of directors of the Institute.

To date, two projects have been referred to the special subcommittee for action: "Stability of Impregnated Paper Insulation," and "Welding Research." In both instances the special subcommittee recommended that the Institute act as sponsor for the projects and that it support them by nominal grants made from Institute funds.

New NEMA Standards Published. New standards entitled "NEMA Motor and Generator Standards," publication 38-49, recently was issued by the National Electrical Manufacturers Association to supersede the previous edition (publication 34-22) which was issued in 1934. Some of the new material published in these standards includes temperature ratings of enclosed motors, standardized lettering for flange-mounted motors, methods of measuring motor vibration, and much of the material contained in the previous standards has been revised and augmented. Copies of the new standards may be obtained from the National Electrical Manufacturers Association, 155 East 44th Street, New York, N. Y., at two dollars per copy.

Graduate Evening Courses at Stevens. For the first time, Stevens Institute of Technology, Hoboken, N. J., will offer during the academic year 1938–39 a program of evening graduate courses in engineering. Co-ordinated groups of related courses are being offered in the fields of mechanical engineering, electrical engineering (specializing in communication) and economics of engineering. With the exception of a few noncredit courses, each course will carry credit in one or more approved programs leading to the degree of master of science.

Lamme Medal Nominations Due December 1

Attention is called again to the opportunity open to any member of the Institute to submit nominations for the 1938 AIEE Lamme Medal. All nominations must be received not later than December 1 (for further particulars, see ELECTRICAL ENGINEERING for June 1938, page 266). The 1937 Lamme Medal was presented to Doctor R. E. Doherty, president, Carnegie Institute of Technology, Pittsburgh, Pa., at the recent AIEE summer convention in Washington, D. C.

CIGRE Offers Full Proceedings of Conclave

Three bound volumes comprising a total of approximately 3,000 pages and including some 863 illustrations covering the 1937 meeting of the Conference Internationale Des Grands Reseaux Electriques are now available, according to an announcement recently received. The announced price is 450 francs (375 francs for permanent members of the CIGRE); interested persons should communicate with the CIGRE, 54, Avenue Marceau, Paris, France.

The Proceedings are published in French and contain the full text of the 119 papers presented, as well as a transcription of the shorthand record of all the discussions. The contents of the three volumes are as follows:

Volume I: Generation, Transformation, and Circuit Breaking. Alternators; parallel running; metering, metering and control instruments; transformers; insulating oils; insulating materials other than oils; switches and circuit breakers.

Volume II: Construction, Insulation, and Maintenance of Overhead and Underground Networks. Cables; overhead conductors; frost and snow, wind; poles and pylone; insulators.

Volume III: Operation, Protection, and Interconnection of Networks. Telephone and radio interference; earthing; organization and operation of networks; lightning and lightning arresters; surges; signaling, remote control and indication; overloads; discriminative protection; safety.

ASTM Awards Dudley Medal. For his paper "Analysis of the Brinell Hardness Test" the American Society for Testing Materials has awarded the Charles B. Dudley Medal for 1938 to Robert H. Heyer, junior metallurgist, research laboratories, The American Rolling Mill Company. This medal, which commemorates the name of the first president of ASTM, is awarded to the author or authors of the paper presented at the preceding annual meeting that is of outstanding merit and constitutes an original contribution on research and engineering material.

Coffin Fellowships. Nine college graduates have been granted Charles A. Coffin fellowships, totaling $5,000, for use in carrying on advanced scientific research during the coming school year, according to a recent announcement. The fellowships were established by the General Electric Company in 1922 to honor its retiring president and founder, and are awarded each year to graduates of colleges in the United States who have shown by the character of their work that they could with advantage undertake or continue research work in educational institutions either in this country or abroad. Among the winners are R. P. Krebs (Enrolled Student) Cincinnati, Ohio, and E. M. Williams (Enrolled Student) Wallingford, Conn. President John C. Parker is AIEE representative on the Charles A. Coffin fellowship and research committee.

"Musa" to Be Used in New Transatlantic Phone Station

A tract of land on the Manahawken Great Meadows in New Jersey over 2,500 acres in extent has been acquired by the American Telephone and Telegraph Company to be used as a receiving station site for the company's transatlantic telephone service, according to an announcement in a recent issue of the *Bell Laboratories Record*. The selection of the tract at Manahawken was dictated by the use of the multiple-unit steerable antenna system which was developed by Laboratories engineers. There will be a series of 16 antenna units in a line about two miles long. This system, known as the "musa," greatly reduces the effect of fading and is highly efficient in separating the desired signal from interfering noises such as static and other electrical disturbances.

The line of antennas will be aimed at the Rugby transmitting station near London, England. The antenna wires will be strung in the form of 16 diamonds, on poles some 65 feet above the ground, each unit antenna being about 450 feet long. Adjacent to the antennas will be a brick building housing the receivers and auxiliary apparatus. The antennas will be connected to the receivers by coaxial cables. The station is expected to be ready for operation by the spring or summer of 1939.

Bennett M. Brigman Memorial. Friends and former students of Bennett Mattingly Brigman, late dean of the Speed Scientific School of the University of Louisville (Ky.), are attempting to create a memorial in his honor. The proposed plan, according to an announcement made by the Bennett M. Brigman Memorial Committee, is to create a permanent and perpetual student loan fund to assist worthy students in attending that school. Dean Brigman received a part of his formal education at the University of Louisville (*EE, Mar. '38, p. 142*) and was appointed to the faculty of the university in 1912. In 1923 he organized the Speed Scientific School of that Institution and was made its dean, a position he held continuously until his death on February 8, 1938.

Proceedings of the Rubber Technology Conference, held in London, England, May 23–25, 1938 has been announced as soon to be available. This volume, said to "represent the forefront of advanced thought in the science and general technology of rubber," is scheduled to contain on its 1,000-odd 9- by 12-inch pages the 103 scientific and technical papers read at the conference, and the important discussions thereon. These papers were prepared by authors representing 16 different countries, and are said to cover "almost every conceivable phase of rubber technology, from the physiology of latex-yielding plants to the marketing of manufactured rubber articles." Several papers deal with the subject of electric power cables. The quoted price is £ 2 2s. Persons interested should correspond directly with the Institution of the Rubber Industry, 12 Whitehall, London, S.W.1, England.

Future Meetings of Other Societies

American Association for the Advancement of Science. Winter meeting, December 27–31, Richmond, Va.

American Chemical Society. Fall meeting, September 5–9, Milwaukee, Wis.

American Gas Association. October 10–14, Atlantic City, N. J.

American Institute of Mining and Metallurgical Engineers. Petroleum division, October 6–7, Los Angeles, Calif.

Industrial minerals division, October 20–21, Los Angeles, Calif.

Coal division (joint meeting with ASME and Western Society of Engineers) October 13–15, Chicago, Ill.

American Physical Society. 223d meeting, November 25–26, Chicago, Ill.

224th meeting, December 1938, Los Angeles, Calif.

Annual meeting, December 26–28, Washington, D. C.

American Society of Mechanical Engineers. Wood industries division, September 22–23, High Point, N. C.

Applied mechanics division, September 28–30, Los Angeles, Calif.

Fall meeting, October 5–7, Providence, R. I.

Fuels division, October 13–15, Chicago, Ill.

American Transit Association. 57th annual convention, September 19–22, Atlantic City, N. J.

Association of Iron and Steel Engineers. Annual convention and iron and steel exposition, September 27–30, Cleveland, Ohio.

International Congress of Applied Mechanics. September 12–16, Cambridge, Mass.

International Management Congress. September 19–23, Washington, D. C.

National Electrical Contractors Association. September 12–15, Detroit, Mich.

National Electrical Manufacturers Association. October 24–28, Chicago, Ill.

National Research Council, Highway Research Board. 18th annual meeting, November 30–December 2, Washington, D. C.

National Metal Congress. October 17–20, Detroit, Mich.

National Safety Congress. Silver jubilee, October 10–14, Chicago, Ill.

Society of Automotive Engineers. National regional fuels and lubricants meeting, October 6–7, Tulsa, Okla.

National aircraft production meeting, October 13–15, Los Angeles, Calif.

Letters to the Editor

CONTRIBUTIONS to these columns are invited from Institute members and subscribers. They should be concise and may deal with technical papers, articles published in previous issues, or other subjects of some general interest and professional importance. ELECTRICAL ENGINEERING will endeavor to publish as many letters as possible, but of necessity reserves the right to publish them in whole or in part, or reject them entirely.

ALL letters submitted for consideration should be the original typewritten copy, double spaced. Any illustrations submitted should be in duplicate, one copy to be an inked drawing but without lettering, and other to be lettered. Captions should be furnished for all illustrations.

STATEMENTS in these letters are expressly understood to be made by the writers; publication here in no wise constitutes endorsement or recognition by the American Institute of Electrical Engineers.

Journals for Electrical Engineers

To the Editor:

In the March issue of ELECTRICAL ENGINEERING (pages 110–13) C. F. Dalziel presents an analysis to facilitate, for an individual or an institution, the selection of the necessary journals dealing with electrical engineering. This analysis is based on the number of references given to these journals in other technical periodicals. The writer takes the liberty to make two objections: against the scope, and against the method of analysis. He wishes to emphasize that his deductions should not be understood as a mere criticism, but as an attempt to clarify the problem and to show a way for another solution.

As to the scope, there seem to be two different problems:

1. To select the most important magazines dealing with electrical engineering in general, if certain limited funds are available. Such a situation might exist in the case of a college or public library.

2. To select the most important magazines for an organization or an individual which works on a special field in the art.

Obviously, the selection as suggested by Mr. Dalziel applies only to the first group. Therefore, the following remarks are confined to this group also.

The method of analysis seems to be questionable in considering the results. The tables indicate that the most important magazines for electrical engineers are those dealing with pure or applied physics. This is certainly incorrect. The result is caused by the fact that the physicist—in general at least—is used to work more scientifically, more systematically, than the engineer. He takes the time to investigate the work previously done on his subject, and he refers to it. Why not admit that this method is not only more scientific, but also more economical because it avoids doing things again which already have been done and published?

Be this as it is, it seems hardly possible to use a method for grading which depends on such complex quantities as educational standard of the reader and his knowledge of foreign languages. Take for instance magazines 10 and 11 of table I, *Elektrische Nachrichten-Technik* (*ENT*) and *Elektrotechnische Zeitschrift* (*ETZ*), both published in the same language. With its 12 issues per year, *ENT* is referred to in foreign magazines 173 times; and the voluminous *ETZ*, with 52 issues per year, only 165 times. Is the *ENT*, then, a more important journal for a public library? Certainly not; but its highly mathematical papers will be studied from, and quoted by, the scientifically trained communication specialists of the whole world, whereas the *ETZ* can be found on the desk of nearly every German electrical engineer. It is pretty much the same relation as exists in the United States between the *Bell System Technical Journal* (with 4 issues per year and 80 references) and *Electrical World* (with 24 technical and 24 news issues, and 109 references).

What is the best way to get rid of such intangible quantities as educational standard? The writer wants to suggest this: to analyze the last two volumes of the *Science Abstracts*, section *B*, electrical engineering. It is merely necessary to count how frequently the various magazines are abstracted. Two consecutive volumes are suggested in order to have the proper count of those important papers presented before the Conférence Internationale des Grand Réseaux Electriques à Haute Tension which meets every two years. As a check, a similar abstracting magazine might be analyzed, for instance, the new German home product *Electrotechnische Berichte*.

Of course, such abstracting magazines deal chiefly with the main technical articles published in the journals under review; but it is this aspect which is in accordance with the interests of a public library. A manufacturing or operating concern, or an individual, might be interested in quite different parts of a journal, as: contracts and tenders, or positions offered and wanted; but a classification or grading from this point of view is certainly beyond the scope of the problem under consideration.

Yours very truly,
LUDWIG F. ROEHMANN (M'37)

(Electrical Engineer, Anaconda Wire & Cable Company, Hastings-on-Hudson, N. Y.)

The Role of the Engineering Library

To the Editor:

The timely article on "The Role of the Engineering Library," by Harrison W. Craver, published in the July issue of ELECTRICAL ENGINEERING (pages 291–4) is interesting and challenging to both educators and engineers in industry.

As the author indicates, the number of books now available is so enormous that careful selection is necessary by most libraries on account of budgetary limitations. Much assistance is being rendered the smaller college libraries by a pamphlet entitled "Selected Bibliography of Engineering Subjects, Section IV, Electrical Engineering and Mechanical Engineering," and published under the auspices of the Engineers Council for Professional Development. A good illustration of a much smaller selection is Lucke's Condensed Library of Engineering.

Particularly in view of the very large number of engineering periodicals now being published, a carefully chosen list of electrical periodicals should be prepared to supplement the selected book bibliographies now existing.

Even though "the library needs of the engineers have received scant attention until recent times," in the words of Doctor Craver definite attempts are now being made by engineering colleges to teach students methods of library usage, and to inculcate in them the "library habit." It was the good fortune of the electrical-engineering division of the Society for the Promotion of Engineering Education, under my chairmanship, to have Mrs. Ruth McG. Lane, Vail Librarian of the Massachusetts Institute of Technology, discuss, at the Cambridge convention in 1937, "The Place of the Technical Library in Engineering Education." This excellent paper is published in the April 1938 issue of the *Journal of Engineering Education*.

Very truly yours,
A. NAETER (A'23, M'30)

(Professor and Head, Department of Electrical Engineering, Oklahoma Agricultural & Mechanical College, Stillwater, Okla.)

Ambient Temperatures for Overloading Transformers

To the Editor:

Because of the increasing demand for full utilization of investment by public utilities, the overloading of transformers on a temperature basis is daily becoming a more fundamental problem in engineering. Several methods have been presented in engineering literature by which overloads may be calculated for specified conditions of winding temperature, load cycle, and ambient temperature. The limiting winding temperature can be determined quite definitely from the known relation between temperature and life of insulation, and the load cycle predicted from previous load readings. The major difficulty lies in the determination of an ambient temperature on which to base the calculations of overload capacity.

During the past year I have done considerable work on this problem and have devised a method based upon the temperature-life equation for insulation in oil by which ambient temperatures for calculating overloads can be determined.

The major limiting feature on the load that a transformer can carry is the temperature that the windings attain under such load, and the length of time that the temperature endures. Since temperature rise over ambient temperature varies as a function of the load, the load that a transformer can safely carry without exceeding a definite limiting total temperature is dependent upon the ambient temperature, the load increasing as the ambient decreases and vice versa. However, it is practically impossible to vary the load day by day to allow for daily variation in ambient temperatures and still maintain the same load-cycle configuration. For this reason it has been decided to use an equivalent ambient temperature on

which to base ratings for various months or periods of the year, which should have the same effect on the life of the transformer as would the actual ambient temperatures that occur during the period in question.

Listed in table I are the equivalent ambient temperatures that have been recommended for use in the vicinity of Philadelphia, Pa. Two values are given for each month or period of the year, one a true and the other an effective ambient temperature to include the effect of the sun in heating a transformer. When peak loads occur between sunrise and sunset, it has been recommended that the effective ambient-under-sun temperature be used. Generally ambient temperatures of 10 degrees centigrade for the winter period (November through March) and 30 degrees centigrade for the summer period (April through October) have been recommended because the yearly load cycle can be divided into these two periods, and because summer peaks usually occur during the day and winter peaks at or shortly after sunset.

According to V. M. Montsinger,[1,2] the life of a transformer out to a time of 20 years can be expressed as a function of the hot-spot temperature at which the transformer operates during that time:

$$Y = 7.15 \times 10^4 \, \epsilon^{(-0.088X)} \qquad (1)$$

where

Y = life in years

X = hot-spot temperature in degrees centigrade

ϵ = base of Naperian logarithms

If the hot-spot temperature (X) is split into two components, the hot-spot rise above ambient (θ), and the ambient temperature (A), this equation may be written

$$Y = \frac{7.15 \times 10^4 \, \epsilon^{(-0.088\theta)}}{B} \qquad (2)$$

where

$$B = \epsilon^{(0.088A)} \qquad (3)$$

The distribution of daily maximum temperatures for each month of the year was obtained from data taken at the United States Weather Bureau covering the past 47 years. These data were tabulated as shown in columns I and II in the appendix, by recording the number of times that the daily maximum temperature occurred between specified limits chosen at fixed intervals. By evaluating B for the mean of each interval and weighting by the number of occurrences in that interval, an average value of B was determined, and from it a value for the equivalent ambient temperature A. This ambient temperature (A) in combination with any fixed value of hot-spot rise (θ) will give the same life for the transformer from equation 2 as that transformer would have for the the same hot-spot rise (θ) in combination with all the ambient temperatures that can occur during that month, each weighted according to the probable frequency of its occurrence. In the appendix is given an example for the temperature distribution of the month of December and the method of calculating the ambient temperature (A) to be used. Ambient temperatures for entire winter and summer periods have been derived in the same fashion as for the individual months.

Table I. Equivalent Ambient Temperatures for Use in Philadelphia, Pa.

Month	True Ambient Temperature (Degrees Centigrade)	Effective Ambient-Under-Sun Temperature (Degrees Centigrade)
January	6	7
February	6	8
March	12	15
April	18	22
May	24	28
June	28	33
July	30	35
August	29	33
September	26	29
October	20	22
November	13	14
December	8	9
Winter Period November through March	10	11
Summer Period April through October	26	30

According to Mr. Montsinger, transformers when operating under the sun during June and July will be from six to eight degrees hotter than if they were in the shade. According to our somewhat approximate calculations taking into account the absorptivity of transformer paint, the average exposed area of a transformer in proportion to its rated losses, and the intensity of solar radiation at the surface of the earth, a figure of seven degrees centigrade seems to be a fairly conservative one for the increase in transformer temperatures due to the sun. By taking into account the percentage of sunshine during the various months in combination with the annual curve of solar intensity at 40 degrees north latitude at the earth's surface, temperatures to be added to the ambient temperatures for each month in order to allow for heating by the sun have been derived in the same way as were the ambient temperatures.

Because the recommended ambient temperatures have been based upon daily maximum temperatures which usually last but two or three hours a day and, therefore, are not usually effective due to the large thermal capacity of transformers, it is believed that these temperatures should form a fairly conservative basis for rating outdoor transformers. A further safety factor in utilizing these ambient temperatures for winter and summer periods is that loads in general are never constant throughout the periods; and with peak ratings based upon these figures, some life will be gained at those times when the load is not up to its peak value.

The results of this analysis have shown that the equivalent ambient temperatures for months or periods of the year will not be exceeded during 60 per cent of the time, thus bringing out the weighted effect of the exponential life equation at higher temperatures; if life were directly proportioned to temperature, it would be possible to use average values throughout. The maximum deviations above the equivalent ambient temperatures are 25 degrees centigrade for the winter period and 17 degrees centigrade for the summer period; and the probability that the actual ambient temperature will be more than 10 degrees centigrade above the equivalent ambient is ten per cent for the winter period and five per cent for the summer period.

Table II. Calculation of Ambient Temperature (A) for Month of December

(I) Daily Maximum Temperature Limits (Deg. F)	(II) No. of Times Daily Maximum Temperature Between Limits of (I)	(III) Average Value of A_F for Limits of (I) (Deg. F)	(IV) Value of $\epsilon^{(0.0489 A_F)}$ for A_F of (III)	(V) Product of (II) by (IV)
9.5–12.5	2	11	1.63	3
12.5–15.5	2	14	1.98	4
15.5–18.5	5	17	2.30	12
18.5–21.5	7	20	2.66	19
21.5–24.5	15	23	3.09	46
24.5–27.5	52	26	3.57	186
27.5–30.5	49	29	4.14	203
30.5–33.5	95	32	4.79	454
33.5–36.5	127	35	5.55	705
36.5–39.5	167	38	6.42	1,072
39.5–42.5	191	41	7.47	1,428
42.5–45.5	166	44	8.60	1,428
45.5–48.5	148	47	9.97	1,476
48.5–51.5	116	50	11.54	1,340
51.5–54.5	91	53	13.40	1,220
54.5–57.5	73	56	15.50	1,132
57.5–60.5	63	59	17.90	1,129
60.5–63.5	34	62	20.80	708
63.5–66.5	18	65	24.10	434
66.5–69.5	5	68	27.90	140
Total	1,426			13,139

Appendix

Because ambient temperatures are measured in degrees Fahrenheit at the Weather Bureau, equation 3 can be rewritten

$$B = \epsilon^{(0.0489 A_F - 1.565)} \qquad (4)$$

or

$$B = 0.209 \, \epsilon^{(0.0489 A_F)} \qquad (5)$$

where

A_F = ambient temperature in degrees Fahrenheit

Table II shows the method used in calculating the average value of B and determining from it the value of A to be used for the month of December.

$$\text{Average } \epsilon^{(0.0489 A_F)} = \frac{13{,}139}{1{,}426} = 9.23$$

From equation 5,

$$B = 0.209 \times 9.23 = 1.930$$

From equation 3, solving for A

$$A = \frac{\log_\epsilon 1.930}{0.088} = 7.5 \text{ degrees centigrade}$$

References

Loading Transformers by Temperature, V. M. Montsinger, AIEE Transactions, volume 49, 1930, pages 776–90.

Temperature Limits for Reactors and Transformers, V. M. Montsinger, AIEE Transactions, volume 57 (January section) 1938, pages 39–44.

Very truly yours,

Raymond J. Woodrow (A'38)

(Junior Engineer, Philadelphia Electric Company, Philadelphia, Pa.)

Personal Items

H. W. Leitch (A'98, M'13) recently was elected vice-president in charge of electrical operations of the Consolidated Edison Company of New York, Inc., New York, N. Y. Mr. Leitch was born in Brooklyn, N. Y., October 31, 1875, was graduated from the Polytechnic Institute of Brooklyn with the degrees of bachelor of science (1894) and electrical engineer (1895), and obtained employment with The New York Edison Company as a dynamo tender in 1895. Later he became successively system operator, chief operator, and assistant superintendent of

H. W. LEITCH

generating stations, before being transferred to the United Electric Light and Power Company as superintendent of the plant in 1913. In 1923 Mr. Leitch was made general superintendent of power plants, and in 1932 became associate chief operating engineer of both the United Electric Light and Power Company and The New York Edison Company. Shortly after the merger of The New York Edison Company into the Consolidated Edison Company of New York, Mr. Leitch was made engineer of operation.

I. H. Sclater (A'08, F'27) has been appointed managing engineer of the power transformer department, General Electric Company, Pittsfield, Mass. A native (1883) of Palmyra, Va., and an electrical engineering graduate of Virginia Polytechnic Institute, Mr. Sclater has been associated with the General Electric Company continuously since 1906, when he entered the company as a test engineer. He was placed in charge of the design of oil-insulated transformers in 1923, and in 1931 became assistant engineer of the transformer-engineering department. He became engineer of that department in 1933.

Philip Torchio (A'95, F'12) vice-president of the Consolidated Edison Company of New York, Inc., New York, N. Y., retired recently. A native of Italy, Mr. Torchio was graduated from the University of Pavia with the degree of bachelor of arts (1890), and from the Royal Polytechnic of Milan with the degrees of mechanical engineer and electrical engineer (1893). He came to the United States in 1893 and was employed by the Sprague Electric Elevator Company as a draftsman. Two years later he was employed as a draftsman by the Edison Electric Illuminating Company of New York, predecessor of The New York Edison Company. In 1899 Mr. Torchio was made statistician, then successively engineer of economics, engineer of distribution, chief electrical engineer; and, in 1924, vice-president in charge of electrical engineering. At that time he acted also as consulting engineer for several affiliated utility companies. Before the merger of The New York Edison Company and the United Electric Light and Power Company, he was senior vice-president and a director of both companies.

E. W. Gorry (A'18) superintendent of the a-c substation operations bureau, Consolidated Edison Company of New York, Inc., New York, N. Y., retired recently after more than 48 years of service. Mr. Gorry was born in New York, September 8, 1873, and obtained his first position with the Westinghouse Electric and Manufacturing Company in 1889. In the following year he was employed by the United Electric Light and Power Company, a predecessor of the Consolidated Edison Company, as an armature winder. Later he became successively assistant foreman of the repair shops, operator, chief operator, operating superintendent, superintendent of the operating department, and superintendent of a-c substations.

L. L. Crump (M'32) has been elected vice-president of the James R. Kearney Corporation, St. Louis, Mo. Born in Centralia, Mo., in 1891, Mr. Crump was graduated from Missouri State University with the degree of bachelor of science in electrical engineering in 1914, following which he became an apprentice for the Emerson Electric Manufacturing Company. In 1915 he be-

L. L. CRUMP

came a construction engineer for the Union Electric Light and Power Company, St. Louis, remaining with that company in various capacities until 1930. In that year he became a design engineer for the W. N. Matthews Corporation, St. Louis. Two years later he became affiliated with the James R. Kearney Corporation, his first position being as design and sales engineer. For the last five years Mr. Crump has been assistant chief engineer of the company.

H. C. Sheldon (A'36) has established his own electrical manufacturing organization under the name of Sheldon Service Corporation, Long Island City, N. Y. Mr. Sheldon was born in Boston, Mass., in 1903 and attended Amherst College before becoming affiliated with the Scoville Manufacturing Company, Waterbury, Conn. During the last eight years Mr. Sheldon has been associated with the Burndy Engineering Company, New York, N. Y., his most recent position being district manager.

L. A. Grettum (A'24) has been elected president of the Northwest Electric Light and Power Association. Following his graduation from the University of Minnesota in 1923, Mr. Grettum was employed in the engineering department of the Mississippi Valley Public Service Company. Since 1933 he has been operating manager of the Eastern Oregon Light and Power Company, Baker, Ore.

Edward Beck (M'35) has been transferred to East Pittsburgh, Pa., as lightning arrester engineer in the switchgear engineering department of the Westinghouse Electric and Manufacturing Company. Formerly Mr. Beck served as a member of the Westinghouse industry engineering department, and as chief engineer of the Westinghouse X-Ray Company, Inc., Long Island City, N. Y.

K. B. McEachron (A'14, F'37) has received the degree of doctor of engineering from Ohio Northern University. Doctor McEachron was graduated from Ohio Northern in 1913. He is director of high-voltage research at the Pittsfield (Mass.) works of the General Electric Company.

E. A. Coomes (A'36) has received an appointment as instructor in physics at the University of Notre Dame, Notre Dame, Ind., where he will direct research in electronics. He recently received the degree of bachelor of science at Massachusetts Institute of Technology.

J. A. M. Lyon (A'38) recently was appointed instructor in electrical engineering at The Johns Hopkins University, Baltimore, Md. Previously Doctor Lyon was engaged in transmission and relay work in the electrical engineering department of the Utility Management Corporation, Reading, Pa.

O. E. Buckley (M'19, F'29) has been made a member at large of The Engineering Foundation Board by the Board of Trustees of the United Engineering Trustees, Inc. Doctor Buckley is executive vice-president of the Bell Telephone Laboratories, Inc., New York, N. Y.

A. W. Robertson (A'27) has been appointed to the board of directors of the National Association of Manufacturers. Mr. Robertson is chairman of the board of directors of the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

H. H. Porter (A'96, M'12) recently was awarded the honorary degree of doctor of engineering by Rensselaer Polytechnic In-

stitute. Doctor Porter is chairman of the board of the American Water Works and Electric Company, New York, N. Y.

H. C. Silent (A'21, M'29) has become an engineer for the Southern California Telephone Company, Los Angeles, Calif. Mr. Silent previously was engineering superintendent of Electrical Research Products, Inc., Hollywood, Calif.

C. D. Poey (A'22, M'37) has become district sales manager of the Art Metal Company, New York, N. Y. Formerly Mr. Poey was chief engineer of the lamp division of the Greist Manufacturing Company, New Haven, Conn.

A. J. Hornfeck (A'37) recently joined the research department of the Bailey Meter Company, Cleveland, Ohio. Previously Mr. Hornfeck was employed in the engineering general department of the General Electric Company, Schenectady, N. Y.

C. F. Schwan (A'37) has become assistant to the chief engineer of the Peerless Electric Company, Warren, Ohio. Mr. Schwan has been a design engineer for the Apex Electrical Manufacturing Company, Cleveland, Ohio.

G. F. Tinkler (A'36) has become assistant personnel examiner for the State of California, with offices at Sacramento. Formerly Mr. Tinkler was general engineer for the Acme Breweries, San Francisco.

K. N. Wilkens (A'37) has become a timekeeper for the L. E. Myers Company, Chicago, Ill. Mr. Wilkens has been an electrician for the Mueller Brass Company, Port Huron, Mich.

J. H. Wyman (A'37) has become factory engineer for the National Union Radio Corporation, Newark, N. J. Mr. Wyman has been production engineer for the Triad Manufacturing Company, Pawtucket, R. I.

I. E. Siewert (A'35) has been transferred to Zanesville as building supervisor for the Ohio Bell Telephone Company. Previously Mr. Siewert was building foreman for the same company at Toledo.

A. E. Hecker (M'30) superintendent of the Poplar Bluff (Mo.) Municipal Light and Water Plant for the last 22 years, has resigned his position.

D. M. Morley (A'38) has become a student engineer for the General Electric Company, Lynn, Mass.

Obituary

Frank William Roller (A'95, M'01, F'12) president of the Roller-Smith Company, New York, N. Y., died August 21, 1938. Colonel Roller was born May 29, 1874, at New York, and was graduated from Lehigh University in 1894 with the degree of mechanical engineer. Shortly after graduation he became associated with J. A. Machado, an electrical contractor in New York. In 1898 he was commissioned assistant engineer, United States Navy, serving on the U.S.S. "Nashville" as assistant engineer and finally as chief engineer during the Spanish-American war. Following honorable discharge, he renewed his association with Mr. Machado in the firm of Machado and Roller, importers of electrical instruments and agents for the Whitney Electrical Instrument Company, Switchboard Equipment Company, and Columbia Meter Company. These companies were taken over by the Roller-Smith Company, which was organized in 1908 with Colonel Roller as president. During the World War he served in the ordnance department, United States Army, in a civilian capacity. At the time of his death he was chairman of the board of the Sarco Company, and commissioned in the Ordnance Reserve Corps. He was a member of the Institute's board of examiners 1903–05, and of the library committee 1905–06.

John Chester Warner (M'34) vice-president of the RCA Manufacturing Company, Inc., Harrison, N. J., was killed in an automobile accident July 21, 1938. Mr. Warner was born February 14, 1896, at Freeport, Ill., and received the degrees of bachelor of arts (1917), master of arts (1921), and master of science in electrical engineering (1925) at Washburn College, University of Kansas, and Union College, respectively. Following his graduation in 1917 he joined the Signal Corps of the United States Army, remaining in that service until 1919, when he was appointed instructor in physics at the University of Kansas. In the following year he was appointed assistant physicist in the National Bureau of Standards at Washington, D. C., but shortly thereafter obtained a position in the research laboratory of the General Electric Company, Schenectady, N. Y. In 1931 he was appointed assistant head of the vacuum-tube engineering department of that company and one year later became manager of the research and development laboratory of the RCA Radiotron Company. He became vice-president in 1934.

Herbert Mygatt Wilcox (M'37) manager of the new-products division of the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., died suddenly July 28, 1938, while he was in New York City on business. Mr. Wilcox was born at Pittsburgh, Pa., November 6, 1882. After attending Princeton University from 1900 to 1902 he transferred to Massachusetts Institute of Technology, from which he was graduated in 1905 with the degree of bachelor of science in chemical engineering. In 1914 he joined the Winchester Repeating Arms Company, serving as an industrial engineer until 1925, when he became vice-president of Electrical Research Products, Inc. In 1936 he resigned to join Paramount Pictures Corporation, and in the following year became associated with the Westinghouse Company.

Walter J. Lackie (A'28) Doble Engineering Company, Medford Hillside, Mass., died May 26, 1938. Mr. Lackie was born January 20, 1875, at Lowell, Mass., and in 1905 became a station operator for J. E. Henry and Sons, Lincoln, N. H. Three years later he became a draft man for the Manchester (N. H.) Traction, Light, and Power Company, and during the World War was master signal electrician in the United States Army. At the end of the War he became a designer for French and Hubbard, Boston, Mass. In 1922 Mr. Lackie joined the staff of the Doble Engineering Company, and except for one year with Stone and Webster he remained with that organization continuously.

William Joseph Dalton (A'24) electrical diagram division of the general drafting bureau, mechanical engineers department, Consolidated Edison Company of New York, Inc., New York, N. Y., died July 9, 1938. Mr. Dalton was born July 18, 1894, in New York. In 1915 he was employed by The New York Edison Company as assistant meter tester, and except for a period of service in the Air Corps of the United States Army during the World War, his employment with the predecessors and affiliated companies of the Consolidated Edison Company was continuous.

Douglas Lyle Furness (A'08) a sales engineer in the industrial department of the General Electric Company, Boston, Mass., died suddenly June 19, 1938. Mr. Furness was born March 16, 1883, at Rochester, N. Y., and was graduated from Harvard University with the degrees of bachelor of arts (1904) and bachelor of science (1905). Immediately following his graduation in 1905 he entered the employ of the General Electric Company as a test engineer. He was engaged in various sales activities of the company for almost 30 years.

Walter Edwin Young (A'19, M'19) manager of the apparatus sales department, Canadian General Electric Company, Ltd., Toronto, Ont., died June 22, 1938. Mr. Young was born in Toronto, May 28, 1886, and received his technical education at the Toronto Technical School. For four years he was associated with the United Electric Company, Ltd. He then joined the Canadian General Electric Company, where he remained for 32 years.

William Morris Mordey (A'91) consulting engineer, London, England, died July 1, 1938, at the age of 82, after a lifetime spent in the development of electromagnetic machinery. During 1908–09 Mr. Mordey was president of the Institution of Electrical Engineers. He was actively engaged in electrical engineering in England and abroad for 56 years. He was the author of numerous scientific papers.

Membership

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. If the applicant has applied for direct admission to a grade higher than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the na-

tional secretary before September 30, 1938, or November 30, 1938, if the applicant resides outside of the United States or Canada.

United States and Canada

Borda, I. W. (Member), Okonite Company, San Francisco, Calif.
Carter, K. G., Utah Power and Light Company, Salt Lake City.
Ein, S., 907 May Street, Hammond, Ind.
Fisher, L. T., United States Engineering Department, Bonneville, Ore.
Hagerty, J. M. J., Memphis Light and Water Division, Memphis, Tenn.
Hancock, E. A. (Member), General Electric Company, Boston, Mass.
Hanley, J. P., Jr. (Member), Florida Power and Light Company, West Palm Beach.
Hudson, A. B., Louisiana Power and Light Company, Sterlington.
Laskey, M. J., Jr., 1101 Yeadon Avenue, Yeadon, Pa.
Lebo, H., 4891 Ogden Street, Detroit, Mich.
Maughmer, G. F., General Electric Company, Los Angeles, Calif.
McIntyre, H. B. (Member), New England Telephone and Telegraph Company, Boston, Mass.
Moore, A. J., General Electric Company, Boston, Mass.
Morgenegg, A. W., General Service Company, Idaho Falls, Idaho.
Murphy, M. (Member), Southwestern Gas and Electric Company, Fayetteville, Ark.
Nace, A. S., Radiart Corporation, Cleveland, Ohio.
Nettleton, F. P., Southern New England Telephone Company, New Haven, Conn.
Pringle, J. A., (Member), General Motors Air Conditioning Division, Hackensack, N. J.
Ricketts, G. B. S., c/o Scott and Bres, New Orleans, La.
Siedd, M. B., General Electric Company, Schenectady, N. Y.
Snadye, A. M., Jr., 214 Ackerman Avenue, Clifton, N. J.
Symonds, R. F. (Member), New England Trawler Equipment Company, East Boston, Mass.
Woodsmall, F. J., Jensen Radio Manufacturing Company, Chicago, Ill.

Total, United States and Canada—23

Elsewhere

Hansson, B. N. (Fellow), Liljeholmens Kabelfabrik, Stockholm 9, Sweden.
Prowse, R. M. (Member), Tata Iron and Steel Company Ltd., Jamshedpur, India.
Sillar, L. G. (Member), Malakand Hydro Electric Scheme, Mardan, N.W.F. Province, India.
Spaethy, E. S., Compania Minera de Oruro, Oruro, Bolivia, S. A.

Total elsewhere—4

Addresses Wanted

A list of members whose mail has been returned by the postal authorities is given below, with the addresses as they now appear on the Institute record. Any member knowing of corrections to these addresses will kindly communicate them at once to the office of the secretary at 33 West 39th St., New York, N. Y.

Ackerson, Cornelius, 2600 West Grand Boulevard, Detroit, Mich.
Barrett, Earl J., Don Pedro Dam, La Grange, Calif.
Cervenka, Frank J., 5736 Midway Park, Chicago, Ill.
De Lay, R. E., 77 Prospect Ave., Long Beach, Calif.
Fetter, Charles H., Electrical Research Products, 250 W. 57th St., New York, N. Y.
Kapell, Sidney M., 3043 Emmons Ave., Brooklyn, N. Y.
Markham, Thomas C., Jr., 55 Hanson Place, Brooklyn, N. Y.
Marshall, Myron B., Jr., 606 State St., Schenectady, N. Y.
Neiman, William E., 4060 Elbertson Street, Elmhurst, N. Y.
Nissat, A. R., in care of Thomas Cook and Son, 2 Place de la Madeleine, Paris, France.
Piltch, Abraham, 2224 Rutaw Place, Baltimore, Md.
Platterer, Alvin, 776 N. Cass St., Milwaukee, Wis.
Powers, Walter H., 603 West Washington, Jackson, Mich.
Renking, H. L., 208 N. Broadway, St. Louis, Mo.
Robison, R. L., 941 E. Northlake Ave., Seattle, Wash.
Shimp, Robert P., 414 Hampton Ave., Wilkinsburg, Pa.
Skina, Fred A., 626 Ash St., Moscow, Idaho.
Thrush, George H., Jr., 595 Union Trust Bldg., Pittsburgh, Pa.
Whitney, T. G., Electrical Research Products, Inc., 250 W. 57th St., New York, N. Y.
Willick, Francis L., 2397 East Grand Boulevard, Detroit, Mich.
Wilson, Alexander, 315 New Birks Bldg., Montreal, Que., Can.

21 Addresses Wanted

Engineering Literature

New Books in the Societies Library

Among the new books received at the Engineering Society Library, New York, recently are the following which have been selected because of their possible interest to the electrical engineer. Unless otherwise specified, books listed have been presented gratis by the publishers. The Institute assumes no responsibility for statements made in the following outlines, information for which is taken from the preface of the book in question.

INTRODUCTION to COLLEGE PHYSICS. By C. M. Kilby. Second Edition New York, D. Van Nostrand Company, 1938. 398 pages, illustrated, 9 by 6 inches, cloth, $2.25. Intended to present a brief course in the fundamentals of physics. The arrangement of material is orthodox. Contains five main sections on mechanics, sound, heat, magnetism and electricity, and light.

HOUSEHOLD ELECTRIC REFRIGERATION. By J. F. Wostrel and J. G. Praetz. New York and London, McGraw-Hill Book Company, 1938. 406 pages, illustrated 9 by 6 inches, cloth, $4.00. A practical manual for refrigeration service men, electricians, salesmen and others interested in the operation, construction, adjustment and servicing of household refrigerators and their control devices.

FUNDAMENTALS of ELECTRICAL ENGINEERING. By M. B. Reed. Scranton, International Textbook Company, 1938. 326 pages, illustrated, 9 by 5 inches, leather, $3.00. An elementary textbook covering the customary electrical quantities and phenomena, including chapters on transients and conduction through gases. In the treatment of electric circuits the double-subscript method now in use for a-c circuits is applied to direct currents.

ELEMENTS OF PHYSICS. By A. W. Smith. Fourth edition New York and London, McGraw-Hill Book Company, 1938. 790 pages, illustrated, 9x6 inches, cloth, $3.75. A revision of a standard textbook on physics, covering mechanics, wave motion and sound, heat, magnetism and electricity, electronics, physical and geometrical optics, radiation and atomic structure. Two new chapters are devoted to nuclear physics and astrophysics.

ELEKTROINSTALLATION in der SIEDLUNG. Vorbilder und Richtlinien für die Klein-, Gärtner- und Bauernsiedlung, edited by Fachausschuss für Haustechnik des VDI. Berlin, VDI-Verlag, 1938. 58 pages, illustrated, 8 by 5 inches, paper, 2 rm. Discusses the proper planning, layout, erection, and design of details for the current distribution system of small villages or farm settlements, including equipment for electrical lighting, heating, and power installations.

ELECTRIC WELDING. By M. H. Potter. Chicago, American Technical Society, 1936. 77 pages, illustrated, 9 by 6 inches, cloth, $1.25. A practical book for the inexperienced welder, describing processes and equipment, methods for various metals, shapes and types of work, the weldability of different metals, and certain special jobs. The last chapter covers power-tube rectifiers and their utilization in welding equipment.

LIST of RETIREMENT UNITS for ELECTRIC UTILITIES, prepared by Committee on Statistics and Accounts of Public Utility Companies of National Association of Railroad and Utilities Commissioners. New York, State Law Reporting Company, 1937. 21 pages, mimeographed, 11 by 9 inches, paper, $0.85; bound $1.00. A supplement to the uniform system of accounts for electric Utilities. Its purpose is to create greater uniformity in accounting for replacements of property and for depreciation by providing more accurate and uniform distinction between replacements which should be classed as property additions and those to be classed as maintenance.

MOTION PICTURE SOUND ENGINEERING, a Series of Lectures presented to the classes enrolled in the courses in Sound Engineering given by the Research Council of the Academy of Motion Picture Arts and Sciences, Hollywood, Calif. New York, D. Van Nostrand Co., 1938. 547 pages, illustrated, 9½ by 6 inches, cloth, $6.00. Material is taken from a series of lectures presented to employees of motion picture studios. Subjects vary from discussions of sound, electricity, and the chemical elements, through the mechanical processes of recording and projecting, to technical descriptions of filters, networks, and amplifiers.

HEARING, Its Psychology and Physiology. By S. S. Stevens and H. Davis. New York, John Wiley and Sons, 1938. 480 pages, illustrated, 9 by 6 inches, leather, $4.50. Discusses fundamentals of the science of sound, analyzes the auditory process, and describes the systematic relations between stimulus and sensation. Offers also a study of the functional anatomy and physiology of the ear.

ELEMENTS of MECHANISM. By P. Schwamb, A. L. Merrill and W. H. James. Fifth edition. New York, John Wiley and Sons, 1938. 400 pages, diagrams, charts, tables, 9 by 6 inches, cloth, $3.50. Intended to give familiarity with the application of the fundamental principles of kinematics in the field of mechanical movements. Discusses vectors, velocity analysis, motion transmission, and the characteristics of transmitters of mechanical power.

ELEMENTARY THERMODYNAMICS. By V. M. Faires. New York, Macmillan Company, 1938. 225 pages, illustrated, 9 by 6 inches, leather, $2.60. A presentation of the topics of importance for short courses in thermodynamics.

PRINCIPLES of ENGINEERING ECONOMY. By E. L. Grant. Revised edition. New York, Ronald Press Company, 1938. 431 pages, diagrams, charts, tables, 8 by 5 inches, cloth, $3.75. Demonstration of a practical technique providing an engineering basis for making economic decisions is the purpose of this book. Explains interest, valuation, and rate of return calculations and discusses the making of estimates for new enterprises, replacement problems, and the planning of future developments.

(The) MIND of the ANCIENT WORLD. By H. N. Wethered. New York, Longmans, Green and Company, 1937. 302 pages, tables, 9 by 6 inches, cloth, $4.00. A review of Pliny's "Natural History," presenting many excerpts from a famous Elizabethan translation with critical comment by the author.

FOUNDATIONS of WIRELESS. By A. L. M. Sowerby. Second edition. London, (The) Wireless World, Iliffe and Sons, Ltd., 1937. 266 pages, illustrated, 8 by 5 inches, cloth, 4s. 6d. plus 5d. postage. An elementary textbook on radio fundamentals and the radio receiver in particular. Discusses circuits, tubes, and the process of detection, and contains new material on negative feedback, automatic tuning and automatic selectivity control.

ESSAYS in SCIENCE and ENGINEERING, compiled by F. Montgomery and L. N. Becklund. Revised edition. New York, Farrar and Rinehart, 1938. 523 pages, charts, tables, 9 by 6 inches, cloth, $2.00. A collection of essays and articles on scientific and technical subjects designed to provide reading material for engineering English courses. The first part comprises a selection of more general essays; the second and larger part consists of "expository models" for various kinds of technical composition.

DIRECT and ALTERNATING CURRENTS, Theory and Machinery. By B. A. Loew. Second edition. New York and London, McGraw-Hill Book Company, 1938. 730 pages, illustrated, 9 by 6 inches, cloth, $4.50. Intended primarily for students desiring a short survey course in the theory of the electric circuit and the operating principles of electric machines. Stresses fundamental principles rather than mere factual information. A-C theory is stressed largely in terms of vectors. Mathematical discussions are omitted or reduced to simple forms.

Engineering Societies Library

39 West 39th Street, New York, N. Y.

MAINTAINED as a public reference library of engineering and the allied sciences, this library is a co-operative activity of the national societies of civil, electrical, mechanical, and mining engineers.

Resources of the library are available also to those unable to visit it in person. Lists of references, copies or translation of articles, and similar assistance may be obtained upon written application, subject only to charges sufficient to cover the cost of the work required.

A collection of modern technical books is available to any member residing in North America at a rental rate of five cents per day per volume, plus transportation charges.

Many other services are obtainable and an inquiry to the director of the library will bring information concerning them.

Officers and Committees for 1938-39

Officers

President

JOHN C. PARKER — New York, N. Y.
(Term expires July 31, 1939)

Junior Past-Presidents

A. M. MacCUTCHEON — Cleveland, Ohio
(Term expires July 31, 1939)
W. H. HARRISON — New York, N. Y.
(Term expires July 31, 1940)

Vice-Presidents

Dist. No.		
2	I. MELVILLE STEIN	Philadelphia, Pa.
4	EDWIN D. WOOD	Louisville, Ky.
6	L. N. McCLELLAN	Denver, Colo.
8	J. P. JOLLYMAN	San Francisco, Calif.
10	M. J. McHENRY	Toronto, Ont.

(Terms expire July 31, 1939)

1	CHESTER L. DAWES	Cambridge, Mass.
3	F. M. FARMER	New York, N. Y.
5	A. H. LOVELL	Ann Arbor, Mich.
7	F. C. BOLTON	College Station, Tex.
9	LESTER R. GAMBLE	Spokane, Wash.

(Terms expire July 31, 1940)

Directors

F. ELLIS JOHNSON — Madison, Wis.
C. R. JONES — New York, N. Y.
W. B. KOUWENHOVEN — Baltimore, Md.
(Terms expire July 31, 1939)

K. B. McEACHRON — Pittsfield, Mass.
C. A. POWEL — East Pittsburgh, Pa.
R. W. SORENSEN — Pasadena, Calif.
(Terms expire July 31, 1940)

C. R. BEARDSLEY — New York, N. Y.
VANNEVAR BUSH — Cambridge, Mass.
F. H. LANE — Chicago, Ill.
(Terms expire July 31, 1941)

L. R. MAPES — Chicago, Ill.
H. S. OSBORNE — New York, N. Y.
D. C. PRINCE — Philadelphia, Pa.
(Terms expire July 31, 1942)

National Treasurer

W. I. SLICHTER — New York, N. Y.
(Term expires July 31, 1939)

National Secretary

H. H. HENLINE — New York, N. Y.
(Term expires July 31, 1939)

General Counsel

Parker & Aaron
20 Exchange Place, New York, N. Y.

Local Honorary Secretaries

AUSTRALIA—V. J. F. Brain, Dept. of Works & Local Govt., Bridge St., Sydney, N. S. W.

BRAZIL, S. A.—F. M. Servos, Rio de Janeiro Tramways Light & Power Co., Rio de Janeiro.

ENGLAND—A. P. M. Fleming, Metropolitan Vickers Electric Co., Trafford Park, Manchester.

FRANCE—A. S. Garfield, 173 Boulevard Haussmann, Paris, 8E.

INDIA, NORTHERN—V. F. Critchley, P.W.D., Electricity Branch, Lahore, Punjab, India.

INDIA, SOUTHERN—N. N. Iengar, The Tata Power Co. Ltd., Bombay House, Fort Bombay, India.

ITALY—Renzo Norsa, Piazza Imerio 8, Milano.

NEW ZEALAND—P. F. Powell, Canterbury College, Christchurch.

SWEDEN—A. F. Enstrom, Ingeniorsvetenskrapsakademien, Stockholm.

TRANSVAAL, AFRICA—W. Elsdon-Dew, P. O. Box 4563, Johannesburg.

General Committees

Executive

John C. Parker, Chm., 4 Irving Place, New York, N. Y.

F. M. Farmer — A. M. MacCutcheon
W. H. Harrison — K. B. McEachron
C. R. Jones — W. I. Slichter

Board of Examiners

F. V. Magalhaes, Chm., Consolidated Edison Co. of New York, Inc., 4 Irving Place, New York, N. Y.
H. E. Farrer, Secy., AIEE, 33 W. 39th St., New York, N. Y.

P. H. Adams — R. H. Marriott
F. E. D'Humy — Alexander Maxwell
Harold Goodwin, Jr. — A. G. Oehler
H. A. Kidder — A. L. Powell
A. E. Knowlton — H. E. Shreeve — D. C. Prince

Code of Principles of Professional Conduct

D. C. Jackson, Chm., 5 Mercer Circle, Cambridge, Mass.

H. V. Carpenter — W. M. Piatt
F. B. Jewett — H. T. Plumb
A. M. MacCutcheon — C. B. Stephens

Columbia University Scholarships

W. I. Slichter, Chm., Columbia University, New York, N. Y.
Francis Blossom — H. C. Carpenter

Constitution and By-Laws

L. W. W. Morrow, Chm., Corning Glass Works, Corning, N. Y.
R. N. Conwell — Everett S. Lee
H. A. Kidder — I. Melville Stein — W. I. Slichter

Economic Status of the Engineer

A. H. Lovell, Chm., University of Michigan, Ann Arbor, Mich.
T. F. Barton — F. M. Feiker
C. O. Bickelhaupt — R. W. Sorensen

Edison Medal

Appointed by the President for term of 5 years

H. B. Gear — L. W. W. Morrow, Chm. — J. B. Whitehead
(Terms expire July 31, 1939)
F. J. Meyer — R. A. Millikan — Marion Penn
(Terms expire July 31, 1940)
G. L. Knight — H. W. Osgood — W. S. Rodman
(Terms expire July 31, 1941)
C. R. Jones — Everett S. Lee — H. S. Osborne
(Terms expire July 31, 1942)
J. W. Barker — N. E. Funk — W. H. Harrison
(Terms expire July 31, 1943)

Appointed by the Board of Directors from its own membership for term of 2 years

C. R. Beardsley — K. B. McEachron
A. M. MacCutcheon
(Terms expire July 31, 1939)
C. L. Dawes — A. H. Lovell — R. W. Sorensen
(Terms expire July 31, 1940)

Ex-officio
John C. Parker, President
W. I. Slichter, National Treasurer
H. H. Henline, National Secretary
(Terms expire July 31, 1939)

Finance

C. R. Jones, Chm., Westinghouse Elec. & Mfg. Co., 150 Broadway, New York, N. Y.
F. M. Farmer — D. C. Prince

Headquarters

O. B. Blackwell, Chm., 463 West St., New York, N. Y.
H. H. Henline — C. R. Jones

Institute Policy

A. M. MacCutcheon, Chm., 1088 Ivanhoe Road, Cleveland, Ohio
C. F. Harding — I. Melville Stein
W. H. Harrison — W. H. Timbie
B. D. Hull — J. B. Whitehead
H. S. Osborne — H. R. Woodrow

Iwadare Foundation

F. B. Jewett, Chm., 195 Broadway, New York, N. Y.
J. W. Barker — H. H. Barnes, Jr.

Lamme Medal

V. Bush, Chm. — C. R. Jones — D. C. Prince
(Terms expire July 31, 1939)
F. J. Chesterman — C. F. Hirshfeld — A. H. Kehoe
(Terms expire July 31, 1940)
E. W. Allen — A. C. Flory — W. B. Kouwenhoven
(Terms expire July 31, 1941)

Legislation Affecting the Engineering Profession

J. B. Thomas, Chm., Texas Electric Service Co., Fort Worth, Tex.
T. F. Barton — F. G. Guldi
C. R. Beardsley — F. M. Gunby
S. E. Caldwell — D. C. Jackson
D. T. Canfield — L. S. Ready
O. J. Ferguson — R. L. Thomas
N. E. Funk — J. M. Todd
Fred Garrison — W. K. Vanderpoel

Membership

R. L. Webb, Chm., Consolidated Edison Co. of New York, Inc., 4 Irving Place, New York, N. Y.
T. F. Ball — L. G. Hamilton
F. C. Bolton — G. L. Hoard
R. O. Brosemer — G. A. Kositzky
P. G. Edwards — C. E. Winn — F. H. McClain

District Vice-Chairmen

C. M. Foust (1) — Nelson R. Love (6)
M. W. Smith (2) — F. J. Meyer (7)
O. C. Brill (3) — F. B. Doolittle (8)
A. S. Anderson (4) — C. C. Boozier (9)
C. A. Cora (5) — A. B. Cooper (10)

Ex-officio
Chairmen of membership committees of all Sections

Planning and Co-ordination

F. M. Farmer, Chm., Electrical Testing Laboratories, 80th St. & East End Ave., New York, N. Y.
R. E. Hellmund — L. W. W. Morrow
H. H. Henline — H. S. Osborne
C. R. Jones — I. Melville Stein — H. H. Race

Prizes, Award of Institute

H. S. Osborne, Chm., American Tel. & Tel. Co., 195 Broadway, New York, N. Y.
J. W. Barker — E. C. Crittenden
I. Melville Stein

Publication

I. Melville Stein, Chm., Leeds & Northrup Co., 4901 Stenton Ave., Philadelphia, Pa.
F. A. Lewis, Secy., AIEE, 33 W. 39th St., New York, N. Y.
J. W. Barker — H. S. Osborne
O. W. Eshbach — H. S. Phelps
H. H. Henline — H. H. Race
A. G. Oehler — M. W. Smith — D. M. Simmons

GENERAL COMMITTEES—Continued

Safety

Wills Maclachlan, Chm., 50 Oakwood Ave., Toronto, Ont.
L. F. Adams — F. V. Magalhaes
Mark Eldredge — C. N. Rakestraw
J. B. Fisken — A. R. Small
F. D. Knight — Frank Thornton, Jr.
W. B. Kouwenhoven — W. C. Wagner
M. G. Lloyd — H. H. Weber — H. S. Warren

Sections

H. H. Race, Chm., Research Laboratory, General Electric Co., Schenectady, N. Y.
M. S. Coover, Secy., Dept. of Elec. Engg., Iowa State College, Ames, Iowa
W. M. Dann — E. T. Mahood
O. W. Holden — W. H. Timbie — I. Melville Stein

Ex-officio

Chairmen of all Institute Sections

Standards

R. E. Hellmund, Chm., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
H. E. Farrer, Secy., AIEE, 33 W. 39th St., New York, N. Y.
W. P. Dobson — J. Franklin Meyer
F. M. Farmer — V. M. Montsinger
C. R. Harte — E. L. Moreland
R. T. Henry — S. H. Mortensen
A. H. Kehoe — R. L. Young — E. B. Paxton

Ex-officio

Chairmen of Working Committees
Chairmen of AIEE delegations on other standardizing bodies or sole representative thereon
President of U.S. National Committee of the International Electrotechnical Commission

Student Branches

R. W. Sorensen, Chm., California Institute of Technology, Pasadena, Calif.
R. H. Dearborn — F. Ellis Johnson
E. E. Dreese — C. W. Ricker
W. C. DuVall — Charles F. Scott
G. A. Irland — E. M. Strong

Ex-officio

Student Branch Counselors

Technical Program

H. S. Osborne, Chm., American Tel. & Tel. Co., 195 Broadway, New York, N. Y.
C. S. Rich, Secy., AIEE, 33 W. 39th St., New York, N. Y.
C. R. Beardsley — L. W. W. Morrow
H. S. Bennion — E. J. O'Connell
A. H. Lovell — M. W. Smith
V. M. Montsinger — T. A. Worcester — I. Melville Stein

Ex-officio

F. M. Farmer, Chairman, Committee on Planning and Co-ordination
Wills Maclachlan, Chairman, Committee on Safety
Chairmen of all technical committees

Transfers

Everett S. Lee, Chm., General Electric Co., Schenectady, N. Y.
F. M. Craft — Harold Goodwin, Jr.
H. C. Don Carlos — F. O. McMillan
F. M. Farmer — E. L. Moreland

Technical Committees

Automatic Stations

H. W. Codding, Chm., Public Service Electric & Gas Co., 80 Park Place, Newark, N. J.
F. F. Ambuhl — G. B. Northup
A. E. Anderson — A. P. Peterson
Raymond B. Arthur — C. F. Publow
A. M. de Bellis — M. E. Reagan
F. S. Douglass — O. J. Rotty
W. W. Edson — Fred E. Snell
Joseph Hellenthal — Garland Stamper
F. H. Lane — L. J. Turley
J. T. Logan — Chester Wallace
L. N. McClellan — W. C. Whitman — H. B. West

Basic Sciences

E. E. Dreese, Chm., Ohio State University, Columbus, Ohio
S. S. Attwood — M. G. Malti
A. Boyajian — K. B. McEachron
W. F. Davidson — K. W. Miller
L. O. Grondahl — G. W. Penney
C. R. Hanna — H. E. Race
H. L. Hazen — J. Slepian
V. Karapetoff — K. Y. Tang
M. J. Kelly — J. D. Tebo
H. P. Lawther, Jr. — A. von Hippel
F. C. Lindvall — Ernst Weber

Liaison Representatives of American Physical Society

Harvey L. Curtis — Leigh Page

Communication

W. L. Everitt, Chm., Ohio State University, Columbus, Ohio
E. J. O'Connell, Secy., American Tel. & Tel. Co., 195 Broadway, New York, N. Y.
H. A. Affel — John R. Martin
C. B. Aiken — F. R. McBerty
A. L. Albert — H. J. Pierce
W. C. Ballard, Jr. — H. Pratt
H. H. Beverage — C. E. Rogers
Edward L. Bowles — Walter G. Rubel
Charles B. Carpenter — M. A. Sawyer
L. W. Chubb — E. R. Shute
John L. Clarke — Arthur Bessey Smith
J. B. Coleman — Burke Smith
H. J. Dible — D. F. Smith
Melville Eastham — H. W. Sundius
E. E. George — A. Hoyt Taylor
G. H. Gray — C. H. Taylor
W. F. Grimes — F. E. Terman
C. B. Jolliffe — H. M. Turner
H. E. Kent — M. P. Weinbach
J. R. MacGregor — W. C. White
S. S. Mackeown — F. A. Wolff
L. R. Mapes — V. K. Zworykin — F. C. Young

Education

J. W. Barker, Chm., Columbia University, New York, N. Y.
Robin Beach — W. J. Miller
H. W. Bibber — A. D. Moore
F. C. Bolton — E. L. Moreland
H. V. Carpenter — R. C. Putnam
M. S. Coover — J. W. Ramsay
E. E. Dreese — A. R. Stevenson, Jr.
A. M. Dudley — E. M. Strong
O. W. Eshbach — F. E. Terman
C. F. Harding — N. L. Towle
F. Ellis Johnson — H. N. Walker
A. S. Langsdorf — R. I. Wilkinson

Electric Welding

W. E. Crawford, Chm., A. O. Smith Corp., Milwaukee, Wis.
C. A. Adams — G. G. Landis
J. H. Blankenbuehler — Hermann Lemp
A. M. Candy — J. C. Lincoln
J. W. Dawson — F. W. Maxsta lt
Saul Dushman — C. L. Pfeiffer
D. D. Ewing — C. A. Powel
K. L. Hansen — Carroll Stansbury
E. A. Hester — H. E. Stoddard
H. M. Hobart — Malcolm Thomson
C. J. Holslag — H. A. Winne — E. H. Vedder

Electrical Machinery

C. M. Laffoon, Chm., Westinghouse Electric & Mfg. Company, East Pittsburgh, Pa.
J. L. Hamilton, Vice-Chm., 1806 Pine St., St. Louis, Mo.
P. L. Alger — S. H. Mortensen
J. E. Clem — F. L. Moser
C. M. Gilt — J. R. North
I. W. Gross — F. D. Phillips
M. S. Hancock — H. V. Putman
F. E. Harrell — P. H. Rutherford
A. P. Hayward — C. C. Shutt
F. Ellis Johnson — J. B. Swering
O. K. Marti — B. R. Teare
V. M. Montsinger — B. Van Ness, Jr.
T. H. Morgan — G. A. Waters

Electrochemistry and Electrometallurgy

M. F. Skinker, Chm., Consolidated Edison Co. of New York, Inc., 55 Johnson St., Brooklyn, N. Y.
J. V. Alfriend, Jr. — C. C. Levy
F. V. Andreae — Allan Monkhouse
E. L. Bailey — J. D. Noyes
C. Dantsizen — R. M. Pfalzgraff
C. L. Dudley — F. O. Schnure
F. W. Godsey, Jr. — W. R. Schofield
W. C. Kalb — N. R. Stansel
W. B. Kouwenhoven — C. P. Yoder

Industrial Power Applications

J. D. Wright, Chm., General Electric Co., Schenectady, N. Y.

(Personnel not completed at time of publication)

Instruments and Measurements

H. C. Koenig, Chm., Electrical Testing Laboratories, 80th St. & East End Ave., New York, N. Y.
C. E. Bathe — A. E. Knowlton
T. M. Blakeslee — W. B. Kouwenhoven
P. A. Borden — Everett S. Lee
H. B. Brooks — L. J. Lunas
A. L. Brownlee — Paul MacGahan
C. T. Burke — H. B. Pratt
J. S. Cruikshank — H. W. Price
E. D. Doyle — H. C. Rankin
W. N. Goodwin, Jr. — E. J. Rutan
C. H. G. Gray — W. J. Shackelton
T. S. Gray — G. M. L. Sommerman
S. S. Green — H. L. Thomson
H. C. Hamilton — H. M. Turner
N. S. Hibshman — H. N. Walker
F. C. Holtz — Joseph Weil
I. F. Kinnard — R. J. Wiseman

Light, Production and Application of

Robin Beach, Chm., Polytechnic Institute of Brooklyn, 99 Livingston Street, Brooklyn, N. Y.
D. W. Atwater — L. A. Hawkins
J. W. Barker — S. G. Hibben
S. K. Barrett — H. H. Higbie
W. T. Blackwell — W. C. Kalb
H. B. Dates — R. D. Mailey
E. E. Dorting — P. S. Millar
C. L. Dows — L. C. Porter
L. R. Gamble — A. L. Powell
C. A. B. Halvorson, Jr. — E. M. Strong
I. A. Yost

Marine Work, Applications to

A. Kennedy, Jr., Chm., General Electric Company, Schenectady, N. Y.
E. C. Alger — W. H. Reed
R. A. Beekman — H. M. Southgate
H. C. Coleman — W. E. Thau
H. F. Harvey, Jr. — A. B. Waller
C. J. Henschel — O. A. Wilde
F. C. Hoelzle — J. L. Wilson
I. H. Osborne — R. J. Wiseman
G. A. Pierce — R. L. Witham
C. A. Powel — W. N. Zippler

Power Generation

Edward C. M. Stahl, Chm., Consolidated Edison Co. of New York, Inc., 4 Irving Place, New York, N. Y.

(Personnel not completed at time of publication)

TECHNICAL COMMITTEES—Continued

Power Transmission and Distribution

R. D. Evans, Chm., Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

Raymond Bailey	E. A. Loew
A. B. Bauhan	J. T. Lusignan, Jr.
D. K. Blake	G. R. Milne
M. O. Bolser	E. W. Oesterreich
A. B. Campbell	J. S. Parsons
J. S. Carroll	H. J. Scholz
C. V. Christie	G. B. Shanklin
Harold Cole	A. E. Silver
C. A. Corney	D. M. Simmons
M. T. Crawford	C. T. Sinclair
A. E. Davison	L. G. Smith
G. E. Dean	Philip Sporn
P. W. Deck	P. B. Stewart
Mark Eldredge	Stanley Stokes
D. D. Ewing	J. J. Torok
E. D. Freeman	H. M. Trueblood
Herman Halperin	W. K. Vanderpoel
Edwin Hansson	C. F. Wagner
K. A. Hawley	H. S. Warren
L. F. Hickernell	L. F. Woodruff
J. P. Jollyman	T. A. Worcester
W. W. Lewis	H. E. Wulfing

Protective Devices

K. B. McEachron, Chm., General Electric Company, 100 Woodlawn Ave., Pittsfield, Mass.

E. H. Bancker	M. G. Lloyd
H. D. Braley	F. R. Longley
W. R. Brownlee	J. R. McFarlin
J. O'R. Coleman	C. W. McGill
H. W. Collins	J. P. McKearin
F. R. Ford	J. W. Milnor
G. W. Gerell	C. A. Muller
I. W. Gross	J. H. Neher
Herman Halperin	J. R. North
F. C. Hanker	D. C. Prince
R. T. Henry	A. H. Schirmer
P. A. Jeanne	H. K. Sels
B. M. Jones	L. G. Smith
R. A. Larner	R. M. Smith
T. G. LeClair	H. R. Stewart
W. A. Lewis	H. R. Summerhayes
H. J. Lingal	J. D. Wood

Research

E. C. Crittenden, Chm., National Bureau of Standards, Washington, D. C.

F. W. Atkinson	V. Karapetoff
R. W. Atkinson	A. E. Kennelly
L. J. Berberich	W. B. Kouwenhoven
Paul L. Betz	F. O. McMillan
A. Boyajian	K. W. Miller
O. B. Buckley	N. M. Oboukhoff
J. S. Carroll	T. D. Owens
L. W. Chubb	K. K. Paluev
F. M. Clark	H. H. Race
M. S. Coover	W. J. Seeley
W. F. Davidson	John M. Smith
M. Eppley	V. G. Smith
Herman Halperin	G. M. L. Sommerman
F. Hamburger, Jr.	T. Spooner
L. A. Hawkins	Ernst Weber
H. M. Hobart	A. J. Williams, Jr.
D. C. Jackson, Jr.	R. J. Wiseman C. H. Willis

Transportation

W. S. H. Hamilton, Chm., New York Central System, 466 Lexington Ave., New York, N. Y.

(Personnel not completed at time of publication)

Institute Representatives

Alfred Noble Prize Committee, ASCE

H. S. Osborne

Am. Assoc. for the Adv. of Science, Council

V. Bush H. S. Osborne

American Committee on Marking of Obstructions to Air Navigation

G. E. Dean H. L. Huber

American Engineering Council, Assembly

C. O. Bickelhaupt John C. Parker
C. F. Harding C. E. Stephens
William McClellan H. H. Henline, *Alternate*

American Standards Assoc., Standards Council

A. M. MacCutcheon V. M. Montsinger
E. L. Moreland

Alternates

R. E. Hellmund H. H. Henline H. S. Osborne

American Stds. Assoc., Board of Directors

H. P. Charlesworth

American Year Book, Advisory Board

H. H. Henline

Charles A. Coffin Fellowship and Research Fund Committee

John C. Parker

Committee of Apparatus Makers and Users, NRC

L. F. Adams

Committee on Heat Transmission, NRC

T. S. Taylor

Committee on Low Voltage Hazards, ASSE-Engg. Section, National Safety Council

A. B. Campbell

Electrical Standards Committee, ASA

R. E. Hellmund V. M. Montsinger
H. S. Osborne

Alternates

H. E. Farrer E. L. Moreland E. B. Paxton

Engineering Foundation Board

F. M. Farmer W. I. Slichter

Engineering Societies Monographs Committee

F. M. Farmer W. I. Slichter

Engineers' Council for Professional Development

F. Ellis Johnson L. W. W. Morrow
Charles F. Scott

(*Continued on page 400*)

Geographical District Executive Committees

District	Chairman (Vice-President, AIEE)	Secretary (District Secretary)	Chairman, District Committee on Student Activities
No. 1—North Eastern	C. L. Dawes, Harvard University, Cambridge, Mass.	R. G. Lorraine, General Electric Co., Schenectady, N. Y.	E. M. Strong, Cornell University, Ithaca, N. Y.
No. 2—Middle Eastern	I. Melville Stein, Leeds & Northrup Co., 4901 Stenton Ave., Philadelphia, Pa.	H. A. Dambly, Philadelphia Electric Co., 900 Sansom St., Philadelphia, Pa.	A. G. Ennis, George Washington University, Washington, D. C.
No. 3—New York City	F. M. Farmer, Electrical Testing Laboratories, 80th St. & East End Ave., New York, N. Y.	George Sutherland, Consolidated Edison Co. of New York, Inc., 4 Irving Place, New York, N. Y.	F. H. Tallman, Cooper Union, New York, N. Y.
No. 4—Southern	Edwin D. Wood, Louisville Gas & Electric Co., 311 W. Chestnut St., Louisville, Ky.	A. S. Hoefflin, Louisville Gas & Electric Co., 311 W. Chestnut St., Louisville, Ky.	E. F. Smith, University of Florida, Gainesville, Fla.
No. 5—Great Lakes	A. H. Lovell, University of Michigan, Ann Arbor, Mich.	A. G. Dewars, Northern States Power Co., 15 S. 5th St., Minneapolis, Minn.	J. H. Bowman, Purdue University, Lafayette, Ind.
No. 6—North Central	L. N. McClellan, U. S. Bureau of Reclamation, 440 Custom House, Denver, Colo.	W. F. McPhail, U.S. Bureau of Reclamation, Custom House, Denver, Colo.	G. H. Sechrist, University of Wyoming, Laramie, Wyo.
No. 7—South West	F. C. Bolton, A. & M. College of Texas, College Station, Tex.	H. C. Dillingham, Box 256, Faculty Exchange, College Station, Tex.	N. D. Rode, A. & M. College of Texas, College Station, Tex.
No. 8—Pacific	J. P. Jollyman, Pacific Gas & Electric Co., 245 Market St., San Francisco, Calif.	A. M. Bohnert, Ohio Brass Co., 1006 Matson Bldg., San Francisco, Calif.	W. G. Angermann, University of Southern California, Los Angeles, Calif.
No. 9—North West	L. R. Gamble, Washington Water Power Co., Spokane, Wash.	H. L. Vincent, E. 916—19th Ave., Spokane, Wash.	A. L. Albert, Oregon State College, Corvallis, Ore.
No. 10—Canada	M. J. McHenry, Canadian General Electric Co., 212 King St. W., Toronto, Ont.	J. M. Thomson, Ferranti Electric Ltd., Mount Dennis, Toronto, Ont.	

Note: Each District executive committee includes also the chairmen and secretaries of all Sections within the District, and the District vice-chairman of the national membership committee.

INSTITUTE REPRESENTATIVES—Continued

Hoover Medal Board of Award

H. H. Barnes, Jr. Gano Dunn Wm. McClellan

John Fritz Medal Board of Award

A. W. Berresford A. M. MacCutcheon
W. H. Harrison J. B. Whitehead

Library Board, United Engineering Trustees, Inc.

W. S. Barstow H. H. Henline, *ex-officio*
W. A. Del Mar W. I. Slichter

National Bureau of Engineering Registration, Advisory Board

W. I. Slichter

Nat'l Fire Protection Assoc., Electrical Committee

F. V. Magalhaes H. S. Warren, *Alternate*

National Fire Waste Council

Wills Maclachlan H. S. Warren

Nat'l Research Council, Division of Engineering & Industrial Research

V. Bush Everett S. Lee J. B. Whitehead
H. H. Henline, *ex-officio*

Research Procedure Com., Engg. Foundation

L. W. Chubb

Thomas Alva Edison Foundation

H. H. Barnes, Jr. Charles F. Scott
L. W. W. Morrow Clayton H. Sharp

United Engineering Trustees, Inc.

H. P. Charlesworth F. M. Farmer
H. R. Woodrow

U.S. National Committee of the International Commission on Illumination

Robin Beach A. E. Kennelly Clayton H. Sharp

U.S. National Committee of the International Electrotechnical Commission

R. E. Hellmund V. M. Montsinger
H. S. Osborne

Alternates

H. E. Farrer E. L. Moreland E. B. Paxton

Commission of Washington Award

H. B. Gear G. G. Post

Student Branches of the Institute

Name and Location	District	Counselor (Member of Faculty)
Akron, Univ. of, Akron, Ohio	2	J. T. Walther
Alabama Polytechnic Inst., Auburn, Ala.	4	W. W. Hill
Alabama, Univ. of, University, Ala.	4	Fred R. Maxwell, Jr.
Arizona, Univ. of, Tucson, Ariz.	8	J. C. Clark
Arkansas, Univ. of, Fayetteville, Ark.	7	A. S. Brown
Armour Inst. of Tech., Chicago, Ill.	5	E. H. Freeman
British Columbia, Univ. of, Vancouver, B. C., Can.	10	W. B. Coulthard
Brooklyn, Poly. Inst. of, Brooklyn, N. Y.	3	C. C. Whipple
Brown Univ., Providence, R. I.	1	F. N. Tompkins
Bucknell Univ., Lewisburg, Pa.	2	G. A. Irland
Calif. Inst. of Tech., Pasadena, Calif.	8	F. C. Lindvall
Calif., Univ., of Berkeley, Calif.	8	Abe Tilles
Carnegie Inst. of Tech., Pittsburgh, Pa.	2	G. R. Patterson
Case School of Applied Science, Cleveland, Ohio	2	J. R. Martin
Catholic Univ. of America, Washington, D. C.	2	T. J. MacKavanagh
Cincinnati, Univ. of, Cincinnati, Ohio	2	L. R. Culver
Clarkson College of Technology, Potsdam, N. Y.	1	A. R. Powers
Clemson Agri. Col., Clemson, S. C.	4	S. R. Rhodes
Colorado State Col. of A. & M. Arts, Fort Collins, Colo.	6	F. B. Beatty
Colorado, Univ. of, Boulder, Colo.	6	H. B. Palmer
Columbia University, New York, N. Y.	3	G. T. Harness
Cooper Union, New York, N. Y.	3	F. H. Tallman
Cornell Univ., Ithaca, N. Y.	1	B. M. Strong
Denver, Univ. of, Denver, Colo.	6	B. E. Cohn
Detroit, Univ. of, Detroit, Mich.	5	H. O. Warner
Drexel Inst. of Tech., Philadelphia, Pa.	2	E. O. Lange
Duke Univ., Durham, N. C.	4	W. J. Seeley
Florida, Univ. of, Gainesville, Fla.	4	E. F. Smith
George Washington Univ., Washington, D. C.	2	A. G. Ennis
Georgia School of Tech., Atlanta, Ga.	4	T. W. Fitzgerald
Harvard Univ., Cambridge, Mass.	1	J. D. Cobine
Idaho, Univ. of, Moscow, Idaho	9	R. H. Hull
Illinois, Univ. of, Urbana, Ill.	5	E. A. Reid
Iowa State Col., Ames, Iowa	5	B. S. Willis
Iowa, Univ. of, Iowa City, Iowa	5	G. F. Corcoran
Johns Hopkins Univ., Baltimore, Md.	2	W. B. Kouwenhoven
Kansas State Col., Manhattan, Kansas	7	E. L. Sitz
Kansas, Univ. of, Lawrence, Kansas	7	E. W. Hamlin
Kentucky, Univ. of, Lexington, Ky.	4	E. A. Bureau
Lafayette Col., Easton, Pa.	2	F. W. Smith
Lehigh Univ., Bethlehem, Pa.	2	Wm. H. Formhals
Lewis Inst., Chicago, Ill.	5	F. A. Rogers
Louisiana State Univ., Baton Rouge, La.	4	M. B. Voorhies
Louisville, Univ. of, Louisville, Ky.	4	S. T. Fife
Maine, Univ. of, Orono, Me.	1	A. S. Hill
Marquette Univ., Milwaukee, Wis.	5	E. W. Kane
Maryland, University of, College Park, Md.	2	L. J. Hodgins
Mass. Inst. of Tech., Cambridge, Mass.	1	Gordon S. Brown
Michigan Col. of Min. & Tech., Houghton, Mich.	5	G. W. Swenson
Michigan State Col., E. Lansing, Mich.	5	M. M. Cory
Michigan, Univ. of, Ann Arbor, Mich.	5	S. S. Attwood
Milwaukee Sch. of Engg., Milwaukee, Wis.	5	E. L. Wiedner
Minnesota, Univ. of, Minneapolis, Minn.	5	J. H. Kuhlmann
Mississippi State Col., State College, Miss.	4	H. C. Simrall
Missouri Sch. of Mines and Met., Rolla, Mo.	7	I. H. Lovett
Missouri, Univ. of, Columbia, Mo.	7	C. M. Wallis
Montana State Col., Bozeman, Mont.	9	C. F. Bowman
Nebraska, Univ. of, Lincoln, Neb.	6	L. A. Bingham
Nevada, Univ. of, Reno, Nev.	8	S. G. Palmer
Newark Col. of Engg., Newark, N. J.	3	C. H. Stephan
New Hampshire, Univ. of, Durham, N. H.	1	L. W. Hitchcock
New Mexico, Univ. of, Albuquerque, N. Mex.	7	H. L. Jones
New York, Col. of the City of, New York, N. Y.	3	Harry Baum
New York Univ., New York, N. Y.	3	H. N. Walker
North Carolina State Col., Raleigh, N. C.	4	R. S. Fouraker
North Carolina, Univ. of, Chapel Hill, N. C.	4	R. F. Stainback
North Dakota Agri. Col., Fargo, N. D.	6	H. S. Rush
North Dakota, Univ. of, Grand Forks, N. D.	6	H. F. Rice
Northeastern Univ., Boston, Mass.	1	R. G. Porter
Northwestern Univ., Evanston, Ill.	5	A. B. Bronwell
Notre Dame, Univ. of, Notre Dame, Ind.	5	J. A. Caparo
Ohio Northern Univ., Ada, Ohio	2	
Ohio State Univ., Columbus, Ohio	2	E. B. Kimberly
Ohio Univ., Athens, Ohio	2	W. M. Young
Oklahoma A. & M. Col., Stillwater, Okla.	7	Albrecht Naeter
Oklahoma, Univ. of, Norman, Okla.	7	C. T. Almquist
Oregon State Col., Corvallis, Ore.	9	A. L. Albert
Pennsylvania State Col., State College, Pa.	2	P. X. Rice
Pennsylvania, Univ. of, Philadelphia, Pa.	2	C. D. Fawcett
Pittsburgh, Univ. of, Pittsburgh, Pa.	2	H. E. Dyche
Porto Rico, Univ. of, Mayagues, P. R.	3	
Pratt Institute, Brooklyn, N. Y.	3	C. C. Carr
Princeton Univ., Princeton, N. J.	2	A. E. Vivell
Purdue Univ., Lafayette, Ind.	5	J. H. Bowman
Rensselaer Poly. Inst., Troy, N. Y.	1	L. C. Holmes
Rhode Island State Col., Kingston, R. I.	1	W. B. Hall
Rice Institute, Houston, Texas	7	J. S. Waters
Rose Poly. Inst., Terre Haute, Ind.	5	C. C. Knipmeyer
Rutgers Univ., New Brunswick, N. J.	3	P. S. Creager
Santa Clara, Univ. of, Santa Clara, Calif.	8	E. F. Peterson
South Carolina, Univ. of, Columbia, S. C.	4	T. F. Ball
South Dakota State Col., Brookings, So. Dak.	6	W. H. Gamble
So. Dak. State Sch. of Mines, Rapid City, So. Dak.	6	J. O. Kammerman
Southern California, Univ. of, Los Angeles, Calif.	8	W. G. Angermann
Southern Methodist Univ., Dallas, Texas	7	E. H. Flath
Stanford Univ., Stanford University, Calif.	8	H. H. Skilling
Stevens Inst. of Tech., Hoboken, N. J.	3	H. C. Roters
Swarthmore Col., Swarthmore, Pa.	2	J. D. McCrumm
Syracuse Univ., Syracuse, N. Y.	1	C. W. Henderson
Tennessee, Univ. of, Knoxville, Tenn.	4	J. G. Tarboux
Texas A. & M. Col., College Station, Texas	7	R. P. Ward
Texas Technological Col., Lubbock, Texas	7	Willard Gray
Texas, Univ. of, Austin, Texas	7	J. W. Ramsay
Tufts Col., Tufts College, Mass.	1	R. A. Walker
Tulane University, New Orleans, La.	4	C. W. Ricker
Union Col., Schenectady, N. Y.	1	G. J. Fiedler
Utah, Univ. of, Salt Lake City, Utah	9	A. L. Taylor
Vermont, Univ. of, Burlington, Vt.	1	R. O. Buchanan
Villanova Col., Villanova, Pa.	2	H. S. Buecke
Virginia Military Inst., Lexington, Va.	4	
Virginia Poly. Inst., Blacksburg, Va.	4	Claudius Lee
Virginia, Univ. of, University, Va.	4	L. R. Quarles
Washington, State Col. of, Pullman, Wash.	9	H. P. Lickey
Washington, Univ. of, Seattle, Wash.	9	R. E. Lindblom
Washington Univ., St. Louis, Mo.	7	R. S. Glasgow
West Virginia Univ., Morgantown, W. Va.	2	A. H. Forman
Wisconsin, Univ. of, Madison, Wis.	5	
Worcester Poly. Inst., Worcester, Mass.	1	V. Siegfried
Wyoming, Univ. of, Laramie, Wyo.	6	G. H. Sechrist
Yale Univ., New Haven, Conn.	1	A. G. Conrad

Total.....120

Local Sections of the Institute

Name	District	When Organized	Membership Aug. 1, 1938	Chairman	Secretary	Secretary's Address
Akron	2	Aug. 12, '20	76	H. L. Brouse	F. A. Green	B. F. Goodrich Co., Akron, Ohio
Alabama	4	May 22, '29	39	Fred R. Maxwell, Jr.	T. H. Mawson	Commonwealth & Southern Corp., 600 N. 18th St., Birmingham, Ala.
Baltimore	2	Dec. 16, '04	201	G. S. Diehl	H. A. Frey	Locke Insulator Corp., Baltimore, Md.
Boston	1	Feb. 13, '03	410	J. G. Patterson	J. M. Murray	79 Sidney St., Cambridge, Mass.
Central Indiana	5	Jan. 12, '12	123	J. M. Webb	J. G. Harden	Indiana Bell Tel. Co., Indianapolis, Ind.
Chicago	5	1893	697	J. A. Fitts	W. F. Daly	Allis Chalmers Mfg. Co., 135 So. La Salle St., Chicago, Ill.
Cincinnati	2	June 30, '20	182	J. A. Noertker	C. D. Coy	Cincinnati & Suburban Bell Tel. Co., 225 E. 4th St., Cincinnati, Ohio
Cleveland	2	Sept. 27, '07	300	W. C. Kalb	L. K. Stringham	Lincoln Electric Co., Cleveland, Ohio
Columbus	2	Mar. 17, '22	87	H. W. Bibber	N. J. Greene	National Electric Coil Co., Columbus, Ohio
Connecticut	1	Apr. 16, '21	267	F. A. Faron	H. W. Sundius	Southern New England Tel. Co., New Haven, Conn.
Dallas	7	May 18, '28	114	E. B. Robertson	C. W. Mier	Southwestern Bell Tel. Co., Dallas, Texas
Denver	6	May 18, '15	168	A. S. Anderson	J. R. Walker	U. S. Bureau of Reclamation, Denver, Colo.
East Tennessee	4	Sept. 2, '36	102	J. E. Housley	R. W. McEver	2824 Tarlton Ave., Knoxville, Tenn.
Erie	2	Jan. 11, '18	67	R. W. Barrell, Jr.	W. D. Bearce	4121 Sassafras St., Erie, Pa.
Florida	4	Jan. 28, '31	68	A. P. Michaels	Joseph Weil	University of Florida, Gainesville, Fla.
Fort Wayne	5	Aug. 14, '08	88	N. L. Winter	C. R. Atkinson	General Electric Co., 1635 Broadway, Fort Wayne, Ind.
Georgia	4	Jan. 14, '04	97	H. G. Harvey	J. M. Flanigen	Georgia Power Co., Atlanta, Ga.
Houston	7	Aug. 7, '28	116	Seth Evans	T. M. Keiller	2406 Broadway, Beaumont, Texas
Iowa	5	June 25, '29	50	George Charlesworth	H. W. Anderson	Iowa State College, Ames, Iowa
Ithaca	1	Oct. 15, '02	47	W. W. Cotner	True McLean	Cornell University, Ithaca, N. Y.
Kansas City	7	Apr. 14, '16	124	R. G. Kloeffler	B. F. Meador	Black & Veatch, 4706 Broadway, Kansas City, Mo.
Lehigh Valley	2	Apr. 16, '21	192	E. F. Weaver	J. E. Treweek	Pennsylvania Power & Light Co., Hazleton, Pa.
Los Angeles	8	May 19, '08	486	David Hall	J. M. Gaylord	306 West Third St., Los Angeles, Calif.
Louisville	4	Oct. 15, '26	50	A. S. Hoefflin	J. M. Houchens	University of Louisville, Belknap Campus, Louisville, Ky.
Lynn	1	Aug. 22, '11	130	E. H. Raddin	L. P. Shildneck	General Electric Co., River Works, Lynn, Mass.
Madison	5	Jan. 8, '09	64	E. D. Ayres	Wm. A. Kuehlthau	3622 Spring Trail, Madison, Wis.
Memphis	4	May 23, '30	53	C. M. McCord	E. J. Biegel	Box 388, Memphis, Tenn.
Mexico	3	June 29, '22	66	C. E. Plumb	C. Santacruz	Apartado 403, Mexico, D. F., Mexico
Michigan	5	Jan. 13, '11	341	R. E. Greene	W. G. Knickerbocker	The Detroit Edison Co., 2000 Second Ave., Detroit, Mich.
Milwaukee	5	Feb. 11, '10	297	W. E. Crawford	Fred Bush	Allis-Chalmers Mfg. Co., Milwaukee, Wis.
Minnesota	5	Apr. 7, '02	83	C. H. Nelson	R. E. Burlingame	Williamson & Williamson, 925 Metropolitan Life Bldg., Minneapolis, Minn.
Montana	9	June 24, '31	39	C. F. Bowman	W. A. Boyer	2921 Edwards St., Butte, Mont.
Muscle Shoals	4	Feb. 18, '38	40	F. E. Bell	Miss M. G. Coyne	Sheffield Hotel, Sheffield, Ala.
Nebraska	6	Jan. 21, '25	58	I. M. Ellestad	O. E. Edison	Station A, Lincoln, Neb.
New Orleans	4	Dec. 8, '33	78	L. T. Frantz	F. E. Johnson	317 Baronne St., New Orleans, La.
New York	3	Dec. 10, '19	3346	A. L. Powell	G. Sutherland	Consolidated Edison Co. of N.Y., Inc., 4 Irving Pl., New York, N.Y.
Niagara Frontier	1	Feb. 10, '25	205	E. J. Rahill	J. H. Milbyer	Buffalo Niagara Elec. Corp., 300 Electric Bldg., Buffalo, N. Y.
North Carolina	4	Mar. 21, '29	78	M. E. Lake	E. C. Dameron	Durham Public Service Co., Durham, N. C.
Oklahoma City	7	Feb. 16, '22	106	G. I. Page	J. L. Jones	1006 Telephone Bldg., 405 No. Broadway, Oklahoma City, Okla.
Philadelphia	2	Feb. 18, '03	580	H. S. Phelps	W. B. Morton	Philadelphia Elec. Co., Edison Bldg., Philadelphia, Pa.
Pittsburgh	2	Oct. 13, '02	503	W. A. Furst	E. W. Oesterreich	Duquesne Light Co., Pittsburgh, Pa.
Pittsfield	1	Mar. 25, '04	166	L. Wetherill	J. L. Cantwell	General Electric Co., Pittsfield, Mass.
Portland	9	May 18, '09	125	C. B. Carpenter	Corbett McLean	Northwestern Elec. Co., Public Service Bldg., Portland, Ore.
Providence	1	Mar. 12, '20	95	R. J. Underwood	O. E. Sawyer	34 Ford St., Providence, R. I.
Rochester	1	Oct. 9, '14	94	C. L. Smith	C. B. Tuites	Mechanics Institute, Rochester, N. Y.
St. Louis	7	Jan. 14, '03	247	L. O. Campbell	E. K. Shively	Union Electric Co. of Missouri, St. Louis, Mo.
San Antonio	7	May 23, '30	37	O. W. Sommers	W. L. Eyres	San Antonio Public Service Co., San Antonio, Texas
San Francisco	8	Dec. 23, '04	457	F. S. Benson	C. V. Fowler	Pacific Tel. & Tel. Co., 140 New Montgomery St., San Francisco, Calif.
Saskatchewan	10	Oct. 14, '25	25	R. W. Jickling	M. L. Haynes	Balfour Technical School, Regina, Sask., Can.
Schenectady	1	Jan. 26, '03	428	C. E. Kilbourne	O. C. Rutledge	General Electric Co., Schenectady, N. Y.
Seattle	9	Jan. 19, '04	156	R. E. Kistler	L. D. Snow	Puget Sound Power & Light Co., Seattle, Wash.
Sharon	2	Dec. 11, '25	79	C. W. Diehl	E. Steinert	Westinghouse Elec. & Mfg. Co., Sharon, Pa.
Spokane	9	Feb. 14, '13	62	H. A. Stingle	H. B. Hodgins	Westinghouse E. & M. Co., S. 158 Monroe St., Spokane, Wash.
Springfield	1	June 29, '22	57	W. O. Henschke	H. D. Griffith	Westinghouse E. & M. Co., 395 Liberty St., Springfield, Mass.
Syracuse	1	Aug. 12, '20	73	W. H. Lawrence	K. N. Cook	2501 Court St., Syracuse, N. Y.
Toledo	2	June 3, '07	78	G. J. Clark	H. R. Daykin	3701 Larchmont Parkway, Toledo, Ohio
Toronto	10	Sept. 30, '03	348	W. J. Gilson	O. W. Titus	Canada Wire & Cable Co., Ltd., Toronto, Ont., Canada
Tulsa	7	Oct. 1, '37	88	R. K. Lane	D. J. Tuepker	Public Service Co. of Oklahoma, Tulsa, Okla.
Urbana	5	Nov. 25, '02	65	W. J. Warren	G. H. Fett	University of Illinois, Urbana, Ill.
Utah	9	Mar. 9, '17	58	J. A. McDonald	A. C. Kelm	Utah Power & Light Co., Salt Lake City, Utah
Vancouver	10	Aug. 22, '11	93	H. J. MacLeod	T. F. Hadwin	B. C. Electric Railway Co., Ltd., Vancouver, B. C., Canada
Virginia	4	May 19, '22	92	J. S. Miller	F. W. Smith	Virginia Electric & Power Co., Richmond, Va.
Washington	2	Apr. 9, '03	280	T. R. Tate	F. M. Defandorf	National Bureau of Standards, Washington, D. C.
Wichita	7	Sept. 16, '37	33	E. E. Powell	W. A. Wolfe	615 No. Delrose Ave., Wichita, Kansas
Worcester	1	Feb. 18, '20	69	T. R. Holton	W. W. Locke	Worcester Polytechnic Institute, Worcester, Mass.

Total 65

Pamphlet Copies of Papers Available

¶ Limited quantities of pamphlet copies of the technical papers listed, representing surplus stock remaining from recent AIEE conventions and District meetings, are still available.

¶ Copies may be purchased, up to the limit of the present stock, by simply checking the numbers of the papers wanted, filling in the other spaces provided in this coupon, and forwarding the coupon together with the required remittance to AIEE headquarters.

¶ Price: If delivered at Institute headquarters—five cents per copy; if purchased by mail—ten cents per copy.

¶ Orders will be filled in order of receipt.

¶ For those who wish to order only a few copies at a time and who wish to avoid the inconvenience of making small remittances by mail, coupon books are available in one-dollar and five-dollar denominations.

ORDER DEPT., AIEE,
33 West 39th Street,
New York, N. Y.

I enclose $..... for which please send me copies of papers checked (10¢ per copy by mail; 5¢ if delivered at headquarters) and ..... coupon books at $..... each (state whether $1 or $5 denomination).

Name—Please Print

Street & Number

City

State

Papers Presented at North Eastern District Meeting, Lenox, Mass., May 18–20, 1938

No.	Authors	Titles of Papers (Some Shortened)
☐ 38-40	McEachron	*Multiple Lightning Strokes—II
☐ 38-41	Lennox & DeBlieux	*A Direct-Current Transformer
☐ 38-42	LaPierre & Mansfield	*Photoelectric Weft-Straightener Control
☐ 38-44	Sporn & Gross	*Protector-Tube Application and Performance on 132-Kv Lines—II
☐ 38-45	Brosman	*System Planning and Operation for Voltage Control
☐ 38-46	Benner & Lunge	*Voltage-Regulating-Equipment Characteristics
☐ 38-47	Landis	*Voltage Regulation and Control of Rural Lines
☐ 38-48	Burrell & Appleton	*The Periodic Voltage Survey as a Basis for Distribution Design
☐ 38-49	Rogers	*Regenerative Tension Control for Paper Winders
☐ 38-50	Bends	*Comparison of Methods of Stopping Squirrel-Cage Induction Motors
☐ 38-51	Von Sothen	*The Application of Capacitors in Industrial Plants
☐ 38-52	Vogel	*Corona Voltages of Typical Transformer Insulation

Papers Presented at Summer Convention, Washington, D. C., June 20–24, 1938

☐ 37-58	Smith & Weygandt	*Double Line-to-Neutral Short Circuit of an Alternator
☐ 37-866	Appleman	*The Cause and Elimination of Noise in Small Motors
☐ 38-53	Calvert	Amplitudes of the MMF Harmonics for Fractional Slot Windings
☐ 38-54	Porter	Positive-Grid Characteristics of Triodes
☐ 38-55	Bewley	Traveling Waves Initiated by Switching
☐ 38-56	Subcomittee Report	Line-Type Lightning-Arrester Performance Data
☐ 38-57	Fonda	The Fundamental Principles of Fluorescence
☐ 38-58	Whitehead	Lightning Protection of 22-Kv Substations
☐ 38-59	Poritsky	Graphical Field-Plotting Methods in Engineering
☐ 38-60	Reagan	A Self-Checking System of Supervisory Control
☐ 38-61	Race	Tests on Oil-Impregnated Paper—III—Fluid Flow
☐ 38-62	Spurck & Strang	A New Multibreak Interrupter for Fast-Clearing Breakers
☐ 38-63	Champe & Von Voigtlander	System Analysis for Petersen Coil Application
☐ 38-64	Gulliksen	A Position Regulator for Paper Slitters
☐ 38-65	Prince & Williams	The Current-Limiting Power Fuse
☐ 38-66	Clem	Application of Capacitance Potential Devices
☐ 38-67	Curry	The Co-ordination of Mathematics and Physics
☐ 38-68	Malti	Mathematics and Physics in Engineering
☐ 38-69	Stanley	An Analysis of the Induction Machine
☐ 38-70	Brownlee & Dent	Remote Control of Network Protectors
☐ 38-71	Bellaschi & Aggers	Radio-Influence Characteristics of Electrical Apparatus
☐ 38-72	Cole	Flashover Characteristics of Transformer Condenser Bushings
☐ 38-73	Terman	Analysis and Design of Harmonic Generators
☐ 38-74	Schelkunoff	Transmission Theory of Spherical Waves
☐ 38-75	Lyman & North	Application of Large Phase-Shifting Transformer
☐ 38-76	Morgan	Co-ordination of Mathematics and Physics With EE Subjects
☐ 38-77	Inglis	Transmission Features of the New Telephone Sets
☐ 38-78	Wahlquist & Taylor	Noise Co-ordination of Rural Power and Telephone Systems
☐ 38-81	Jones	Instruments for the New Telephone Sets
☐ 38-82	Teare	A Course to Develop Facility in Mathematics and Physics
☐ 38-83	Bryant	Co-ordination of Physics With Electrical Engineering
☐ 38-84	Sporn & St. Clair	Tests and Performance of a High-Speed Multibreak Breaker
☐ 38-85	Dickinson	"De-ion" Air Circuit Breakers
☐ 38-86	Sandin	Enclosed Low-Voltage "De-ion" Breaker of High Capacity
☐ 38-87	Treanor	The Wound-Core Distribution Transformer
☐ 38-88	Sorensen	The Economic Status of the Engineer
☐ 38-90	Williams	Combined Thyratron and Tachometer Control of Small Motors
☐ 38-91	Summers	A Static Constant-Current Circuit
☐ 38-92	Hazeltine	Basic Equations for Electric and Sound Radiation
☐ 38-93	Inman & Thayer	Low-Voltage Fluorescent Lamps
☐ 38-94	McDermott	High-Voltage Gaseous and Fluorescent Tubes
☐ 38-95	Pakala	A Memory Attachment for Oscilloscopes
☐ 38-96	Kouwenhoven & Lotz	Absolute Power Factor of Air Capacitors
☐ 38-97	Rusher & Mershon	The Electric Strain Gauge
☐ 38-98	Concordia, Crary & Lyons	Stability Characteristics of Turbine Generators

Papers Presented at Pacific Coast Convention, Portland, Ore., August 9–12, 1938

☐ 38-43	Lightning Arrester Subcom.	Testing and Application of Lightning Arresters
☐ 38-99	Monroe	Electrification of the San Fracnisco-Oakland Bay Bridge Railway
☐ 38-100	Whelchel	Trends in Electrical Equipment in Hydraulic Power Plants
☐ 38-101	McMillan	Polarity Limits of the Sphere Gap
☐ 38-102	Smith	Use of Bismuth Bridge Magnetic Fluxmeter for A-C Fields
☐ 38-103	Shuck	A Variable-Register-Ratio Watt-Hour Meter
☐ 38-104	Thomson	Similitude of Critical Conditions in Ferroresonant Circuits
☐ 38-105	Morris	Application of Copper-Oxide Rectifiers
☐ 38-106	Wagner	Self-Excitation of Induction Motors
☐ 38-107	Ager	Determination of Induction-Motor Performance
☐ 38-108	Dalziel	Static Power Limits of Synchronous Machines
☐ 38-109	Peterson	General Operation of Transmission Line
☐ 38-110	Cozzens & Peterson	Corona Experience on Transmission Line
☐ 38-111	Cozzens	Insulation and Lightning Protection
☐ 38-112	Laughlin	Carrier-Current Equipment
☐ 38-113	Draper	Transmision-Line Relay Protection
☐ 38-114	Skellett	Narrow-Band Transmission System for Animated Line Images
☐ 38-115	Norwine	Controlling Amplitude Characteristics of Telephone Signals
☐ 38-116	Gaylord	The Pumping System of the Colorado River Aqueduct
☐ 38-117	Skilling	The Electrical Strength of Air at High Pressure
☐ 38-118	Pierce and Hamilton	Phase-Angle Control of System Interconnections
☐ 38-119	Lyon	The Electrostatic Unbalance of Transmission Lines

* These papers have been published in the TRANSACTIONS section of ELECTRICAL ENGINEERING

Transactions
Papers and Discussions Comprising Pages 493–558 of the 1938 Volume

System Planning and Operation for Voltage Control

By T. J. BROSNAN
MEMBER AIEE

THE two criteria of the performance of any system for the delivery of electric energy are, first, its dependability as measured by continuity of service, and second, the quality of the service as measured primarily by the ability of the system to keep the deviations from normal voltage within acceptable limits. The purpose of this paper is to consider the influence of the second of these two factors, namely voltage regulation, on the design and operation of the system.

The permissible limits of voltage regulation vary for different types of load. It is generally regarded as good practice to keep the voltage at the service switches of residential and commercial customers in an urban area within three per cent above or below the normal level. For the same type of customers in rural areas, it is economically impractical to limit the deviations to less than five per cent above or below normal voltage. Industrial customers in general do not require such close regulation.

The following sections of this paper will review the influence of these limitations on the design and operation of the various parts of the system.

General System

In a typical modern distribution system the same subtransmission circuits serve different types of substations as well as transformer vaults in the low-voltage network system.[1] Provision is made for control of the voltage at the bus of the generating or terminal station but the difference in time characteristics of the various loads and the different electrical characteristics of the distribution systems make it essential to supplement this basic regulation with other methods of voltage control.

The generating-station bus voltage is regulated to meet the requirements of the load supplied through the low-voltage network system and provision is made for independent voltage control at the substations supplying residential, small commercial, and small industrial loads. Generally the large industrial loads do not require such close voltage regulation and it is unnecessary to add supplementary voltage control in the substations supplying such loads.

Substations

Automatic substation equipment has made it economically possible to use smaller substations which can be located relatively close together and near large concentrated loads.[2] The close spacing of substations results in short distribution feeders which in turn permit automatic regulation of the substation bus voltage rather than independent regulation of the voltage of each feeder.

In regulating the voltage of the substation bus, it is desirable to introduce a "rising characteristic" with increasing load in order to offset the increasing voltage drop in the distribution system beyond the substation. The "line drop compensator" which has been used for years for this purpose with individual feeder regulators can still be used with the equipment for bus regulation. The setting of "line drop compensators" even for individual feeder regulation involves a compromise between the customers closest electrically to the substation and those farthest removed electrically. With short feeders and bus regulation the problem is no more difficult. The "line drop compensators" are adjusted to give the best average regulation for all of the customers on one small substation instead of one long feeder. The one satisfactory method of keeping the "line drop compensators" properly adjusted in either case is by periodic checking of service voltages of customers close to and remote from the substation during the heavy load periods.

The actual line-to-neutral voltages on the busses of the small automatic substations in Buffalo range from 2,420 at periods of very light load to 2,500 at the time of heavy load. In terms of service voltage this is a range of 121 volts to 125 volts.

Distribution Feeders

There may be a few feeders where the voltage along the entire length of the feeder cannot be kept within the desired limits by means of regulation of the substation bus voltage. For such cases there are several types of feeder-voltage regulating equipment available for pole-top mounting. These can be inserted in any part of the feeder where they will be of greatest value in supplementing bus regulation.

It is evident from the foregoing that it is important to keep the voltage drop in all feeders supplied from one substation within a limited range. The total drop in voltage along a feeder is a function of its length, the magnitude and distribution of its load, its voltage rating, and the size and spacing of the conductors making up the feeder. The proper balance of these factors varies for different load areas. The following combination has been found satisfactory for the urban Buffalo area.

(*a*) All feeders are rated 4,100 volts, three phase, four wire. This system has the advantage of a voltage rating that is satisfactorily high for urban conditions and yet requires only 2,400-volt distribution transformers and incidental equipment. It has its main application in urban areas where all main portions of the feeders are three phase and all single-phase branches are short.

(*b*) The main "trunk" portion of every feeder is made up of 4/0 conductors. This

Paper number 38-45, recommended by the AIEE committee on power transmission and distribution, and presented at the AIEE North Eastern District meeting, Lenox, Mass., May 18–20, 1938. Manuscript submitted March 23, 1938; made available for preprinting April 19, 1938.

T. J. BROSNAN is distribution engineer, Buffalo Niagara Electric Corporation, Buffalo, N. Y.

1. For all numbered references, see list at end of paper.

uniformity in conductor size facilitates rearrangement of feeders and simplifies the transferring of load from one feeder to another under emergency conditions.

(c) The load on each feeder is adjusted according to the length of the feeder so as to make the load multiplied by the distance to the load center as near a constant as possible for all the feeders out of one substation. Under the conditions prevailing in the Buffalo area, the maximum normal feeder loads vary from 800 kva to 1,200 kva.

For suburban and rural areas the 4,800-volt three-phase three-wire delta-connected feeders are more satisfactory than the 4,100-volt star-connected feeders because the single-phase branches form such a large part of rural feeders and it is very desirable to have the higher phase-to-phase voltage for these long branches.

Load balance between phases is very important on all three-phase feeders but particularly on three-phase four-wire star-connected feeders. This load balance should be maintained along the feeder as well as at the substations. The following system has been established for the control of this load balance in the Buffalo district.

A single-line diagram for each feeder indicates the phase to which each distribution transformer is connected and there is marked on this diagram the theoretical load balance at key points along the feeder. Whenever a new distribution transformer is added, the feeder diagram is used to decide the phase to which the new transformer will be connected. In this way all routine work tends to improve feeder balance. The theoretical over-all load balance of a feeder as taken from the diagram is checked periodically by the readings of the maximum-demand meters on each phase of each feeder at the substation.

Transformers, Secondaries, and Services

Any condition in a primary feeder resulting in poor voltage is serious because of the number of customers involved. However, as a result of the care that is taken in the design and operation of distribution feeders in a modern system, they are seldom the cause of poor voltage. The portion of the system that provides the real problem in voltage control is that made up of the distribution transformers, secondaries, and services because the voltage drops in these parts of the system are generally greater than in the short primary feeders in a modern distribution system.

There are so many distribution transformers, secondaries, and services in a distribution system that it is apparent each of these units cannot be given continuous individual attention. Yet, since any one unit when improperly designed, applied, or maintained may be the cause of poor voltage, it is evident that a careful set of standard designs and system of routine attention must be established to insure proper voltage control.

The importance of transformers, secondaries, and services in the voltage problem is further emphasized by a consideration of voltage complaints in the Buffalo district during 1937. Table I shows the number of cases of unsatisfactory voltage caused by each part of the distribution system.

Table I. Number of Justifiable Complaints by Cause During 1937

Portion of System Responsible for Poor Voltage	Number of Complaints	Per Cent of Total
Primary feeders	10	12.3
Transformers and secondaries	27	33.4
Services and customer wiring	30	37.0
Utilization equipment (oil burners, blower motors, flashing signs, etc.)	14	17.3
Total	81	100

The first important step to be taken in guarding against voltage troubles in the secondary portion of the distribution system is to prepare standard transformer-secondary designs for all conditions usually encountered in the field. Such standards must be based not only on proper voltage control but also on considerations of economy, ease of change when necessitated by load growth, and similar factors.

Such a set of standards prepared for the Buffalo district calls for number 2 wire for about 90 per cent of the secondaries. This means that growth of load in the great majority of cases can be accommodated by changing the size or spacing of transformers with no change of secondary wire. These standards are all based on keeping the voltage drop in the secondary within 1.5 per cent with full load on the transformer.

It is equally important to prepare standards for new service entrances to be installed by customers and corresponding service drops to be installed by the power company. This should include guides for the replacement of existing services when necessitated by load increases.

Much could be said about various methods for keeping continuous records for load so as to know when to change transformers. It is mentioned here because whatever system is adopted for field checking transformer loads should also check load balance on the three wire secondaries which is a very important factor in proper voltage control.

Utilization Equipment

Two characteristics of the new load being added to distribution systems today are disturbing to those engineers responsible for proper regulation of service voltages. The first is the low-power-factor characteristic of a large portion of the load that is being added. The second is the tendency of many of the new utilization devices to introduce sudden load changes which, if of sufficient magnitude and of frequent enough occurrence, may result in objectionable flicker. These statements refer particularly to automatic house-heating equipment, air-conditioning equipment, refrigerators, small arc welders, and similar types of apparatus.

It is becoming increasingly important, as more of this equipment is being added to the systems, that the electrical manufacturers, electrical contractors, and electric power companies co-operate to insure the proper operation of this equipment without interference with other loads and at the lowest over-all cost to the industry.

One of the most important steps in such a co-operative program should be the introduction by all electric power companies of reasonable motor-starting-current limitations based on the true capacity of the distribution systems to accommodate such starting currents without serious voltage disturbance in place of limitations based on the size of the motor.[8]

Conclusion

While voltage regulation is the most important criterion of the quality of the service rendered by an electric delivery system, very few customers purchasing electric service have any means for measuring this quality other than by comparison of present with past performance of their utilization equipment. If their lamps seem to burn out at a faster rate than normal, they conclude that the voltage is too high. If the lamps burn with less brilliance than normal or the elements of the range heat at less than normal rate, they conclude that the voltage is too low. This introduces an important psychological factor. For example, an analysis of the voltage com-

Regenerative Tension Control for Paper Winders

By H. W. ROGERS
ASSOCIATE AIEE

THE WINDER is one of the more important machines in the paper industry. In general, every paper machine has a winder intimately associated with it and there are many others used in the finishing room.

It is not strictly a part of the paper machine, but is very closely allied to it since its function is to take the reel of paper from the paper machine, trim it, slit it to the proper width, and rewind it into smooth, even density rolls of the proper size for shipment; and since it starts and stops frequently to change rolls or make splices, it must operate at speeds greatly in excess of the paper-machine speed to keep up with production.

The Winder

It consists essentially of an unwinding stand on which the roll of paper to be rewound is mounted, several free-running steel rolls over which the paper passes, a slitter, a spreader bar, and a pair of winding drums on which the roll of rewound paper rides. See figure 1.

Power is applied to the winding drums, which in many instances have been either geared or belted together in such a manner that the leading roll travels slightly faster than the trailing roll. The object of this method of drive is to wind a uniformly tight roll of proper density.

More recently there has been a definite trend toward using a separate motor on each winding roll, with provision for adjusting the relative load on each motor, thus insuring the proper winding conditions at all times for any kind of paper.

To operate successfully, and wind smooth even density rolls, there must be tension in the sheet of paper. The object of the tension and the spreader bar is two-fold: first, to remove all wrinkles from the sheet, and second, to wind a tight roll of even density. Heretofore, tension has been obtained by means of a manually adjusted band brake on the unwinding roll stand, and while it is possible to automatically control the brake, it is difficult to hold constant tension with such a device since the unwinding roll may vary in diameter as much as five to one during the operation. In a large majority of cases, this band brake is manually operated and in such instances it is impossible to hold anything that approaches constant tension, since the operator has no real indication of the tension in the sheet.

Devices of this type are, of course, in operation, and will continue on the smaller machines, possibly on the larger machines winding light-weight papers, but the trend toward wider, high-speed machines and heavier papers has so increased the power involved that the dissipation of heat in a mechanical brake is a real problem and the maintenance may become a major item of expense.

Characteristics of Paper

The situation may be more readily appreciated if we go back to fundamentals

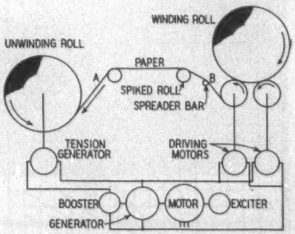


Figure 1. Diagram of a paper winder

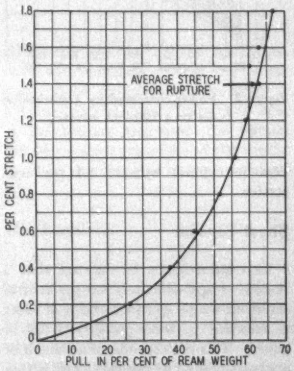


Figure 2. Characteristic stretch curve for uncalendered kraft paper

and discover some of the characteristics of paper. Figure 2 shows the relation between per cent stretch and pounds pull per inch width in per cent of ream weight, (500 sheets, 24 by 36 inches) for uncalendered kraft paper, and while this curve may vary for other grades of paper,

---

plaints received from customers in the Buffalo district during 1937 shows that only 3.5 per cent of the high voltage complaints were justified whereas 80 per cent of the low voltage and flickering voltage complaints were justified.

There has been a very interesting example in the Buffalo district of the effect that major system changes can have on the psychological factor. During the years 1930 and 1931, the supply to all of the residential load and most of the commercial load in the Buffalo district was changed from 25 cycles to 60 cycles. A complete new distribution system was installed and the normal service voltage was raised from 115 to 120 volts as a part of the same operation. The number of voltage complaints rose steadily during this major change reaching a peak during the year 1932 at about double the number recorded in any year prior to the start of the change. There has been an appreciable decrease each year since 1932 so that the total number of complaints during 1937 was only one-quarter of the 1932 peak. The interesting feature is that during this entire period there has been very little change in the annual number of complaints found to be justified.

References

1. FUNDAMENTALS OF DESIGN OF ELECTRIC ENERGY DELIVERY SYSTEMS, J. Allen Johnson and R. T. Henry. ELECTRICAL ENGINEERING, December 1933.

2. 100,000 KW DISTRIBUTION SYSTEM AS A SINGLE PROJECT, R. T. Henry. *Electrical World*, July 25, 1931.

3. MOTOR STARTING CURRENT STEPS BASED ON CONNECTED LOAD, T. J. Brosnan. *Electrical World*, April 28, 1934.

Paper number 38-49, recommended by the AIEE committee on general power applications and presented at the AIEE North Eastern District meeting, Lenox, Mass., May 18-20, 1938. Manuscript submitted February 19, 1938; made available for preprinting April 22, 1938.

H. W. ROGERS is engineer in charge of the industrial manufacturers section of the General Electric Company, Schenectady, N. Y.

it is undoubtedly characteristic of all grades of paper. It is based on some 18 samples varying in weight from 25 pounds to 70 pounds. A few samples ruptured at 1.8 per cent stretch, none ruptured at less than 1.0 per cent stretch and the average rupture was at 1.4 per cent stretch.

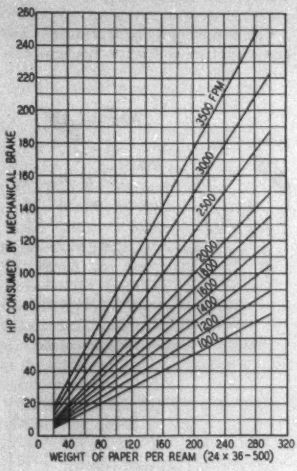


Figure 3. Power consumed by a mechanical brake on a 200-inch winder

Sheet Tension

Experience seems to indicate that a tension of approximately 4.0 per cent of the ream weight per inch width of sheet is sufficient to wind properly a roll of paper. This corresponds to a stretch of approximately 0.02 per cent, well within the rupture point, and up to the present time seems to have met all operating requirements.

Losses Due to Tension

This tension, expressed in pounds pull per inch width of sheet may not appear imposing, but when combined with a wide sheet and high speed, it presents a materially different picture. Figure 3 shows the power consumed by a mechanical brake in maintaining proper sheet tension on a 200-inch-width winder when operating at various speeds with different weights of paper. It also approximates the amount of power returned to the line on a regenerative electric tension-control system.

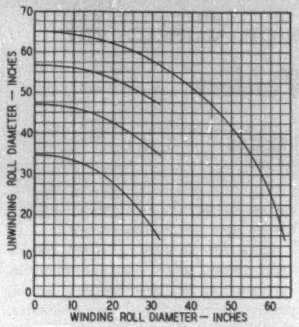


Figure 4. Corresponding diameters of winding and unwinding rolls for paper winders

Regenerative Tension Control

The idea of regenerative tension control is not new, but the enormous expansion of the paper industry, the building of many new kraft mills in the South and the more general use of this kind of paper for containers and innumerable other uses has fostered many changes and developments in this type of equipment to meet the more exacting conditions of operation.

Operating Requirements

The operation of a winder requires a smooth, easy start, continuous slow speed while paper is being threaded through the machine and for making splices, smooth acceleration from standstill to maximum speed, rapid smooth deceleration, and at times, a quick stop.

With the mechanical tension control the operator must rotate the unwinding roll by hand during the threading operation. This is not objectionable on the smaller machines, but the trend toward wider machines and much larger diameter paper rolls places a burden on the operator as some of these rolls weigh six or seven tons. Provision should therefore be made to turn these rolls over by power during the threading operation.

Furthermore, these heavy rolls of paper have an enormous amount of energy when the winder is running at full speed, and provision for quick stopping is essential.

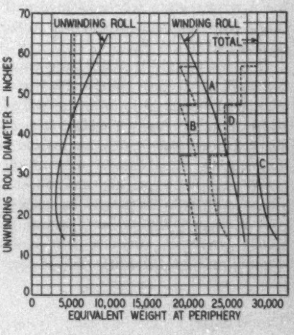


Figure 5. WR^2 of winder reduced to equivalent weight at the periphery

The Modern Winder Drive

One of the modern high-speed winder drives is of the Ward Leonard type with two compound-wound d-c driving motors, a d-c tension generator, a motor generator with booster unit and exciter, the necessary control and a current regulator. The control of the winder speed

Table I. Acceleration Data for a 228-Inch 3,000-Foot-Per-Minute Winder

	Total Machine			Unwinding Roll		
Diameter of Unwinding Roll (Inches)	Equivalent Weight (Pounds)*	Force to Accelerate	Horsepower Torque to Accelerate One Roll	Equivalent Weight (Pounds)	Force to Accelerate	Horsepower Torque to Accelerate
65	28,875	2,245	204	9,750	758	69
60	28,800	2,240	203.5	8,500	641	58.2
55	28,750	2,235	203	7,375	572	52
50	28,750	2,235	203	6,250	486	44.2
45	28,750	2,235	203	5,300	412	37.5
40	28,750	2,235	203	4,500	350	31.8
35	28,750	2,235	203	3,800	295	26.8
30	28,875	2,245	204	3,375	262	23.8
25	29,250	2,270	206.5	3,125	243	22.1
20	29,750	2,310	210	3,125	243	22.1
13.875	31,250	2,430	221	4,125	321	29.1

* Winding one large roll of paper from one 65-inch roll.

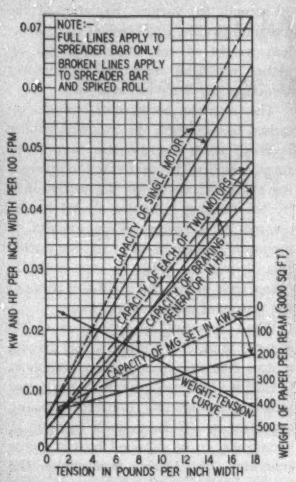

NOTE:-
FULL LINES APPLY TO SPREADER BAR ONLY
BROKEN LINES APPLY TO SPREADER BAR AND SPIKED ROLL
CAPACITY OF SINGLE MOTOR
CAPACITY OF EACH OF TWIN MOTORS
CAPACITY OF BRAKING GENERATOR IN KW
CAPACITY OF M-G SET IN KW
WEIGHT-TENSION CURVE
KW AND HP PER INCH WIDTH PER 100 FPM
WEIGHT OF PAPER PER REAM (3000 SQ FT)
TENSION IN POUNDS PER INCH WIDTH
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0 2 4 6 8 10 12 14 16 18
0 100 200 300 400 500

Figure 6. Power curves for selecting equipment capacity

Figure 7. 234-inch, two-drum winder driven by an adjustable generator voltage winder drive with regenerative braking tension control. Winding speed 3,000 feet per minute

is entirely by generator-field adjustment, and there is means of adjusting the load distribution between the two driving motors to insure a tightly wound roll with any grade of paper.

The Tension Generator

The braking generator is very similar to the adjustable-speed d-c motor with a speed range by field control of four or five to one depending on the maximum and minimum diameter of the unwinding roll. The four-to-one range is, however, less expensive and should be adhered to preferably. This can be accomplished very readily by increasing the core diameter of the unwinding roll a few inches, as it does not affect the maximum diameter materially, nor the amount of paper in the roll.

The Booster

The booster supplies the *IR* drop in the braking generator circuit and makes sheet tension immediately available when the winder is started up. Constant tension means constant horsepower or constant current for any given speed, but since with constant tension the horsepower varies directly with the speed, it follows that if constant current is held in the braking generator, the tension will be constant regardless of the winder speed or the diameter of the unwinding roll.

The Regulator

It is the function of the regulator to hold this current constant at whatever value it is set, depending upon the weight of paper being wound. Provision is made, however, for operating the braking generator as a motor during the threading operation, thus relieving the operator of considerable heavy labor.

Acceleration and Deceleration

Mention has already been made of the heavy inertia involved in large rolls of paper and since the sheet must bring the unwinding roll up to speed and involves considerable tension or pull, the regulator automatically eases off the current held by the braking generator to avoid breaking the sheet and when the winder is up to speed, it again holds the correct current. During the slowing down operation, the reverse is true; the regulator automatically holds a higher current to keep the sheet tight and prevent it from wrinkling.

Table II. Power Data for Winders

*Power Data—With Spreader Bar Only

Tension at "A"**	Tension at "B"**	Friction Load	Tension Load	Total Load	Horsepower Returned	Main Generator Capacity	Tension Generator Capacity
0	0	0.00520	0.00000	0.00520	0.00000	0.00430	0.00000
2	2.163	0.00570	0.00606	0.01176	0.00575	0.00570	0.00517
4	4.326	0.00619	0.01210	0.01830	0.01150	0.00660	0.01035
6	6.489	0.00668	0.01820	0.02488	0.01730	0.00770	0.01550
8	8.652	0.00718	0.02420	0.03138	0.02300	0.00880	0.02070
10	10.815	0.00767	0.03030	0.03800	0.02880	0.00992	0.02600
12	12.978	0.00816	0.03640	0.04456	0.03460	0.01120	0.03120
14	15.141	0.00866	0.04240	0.05106	0.04030	0.01220	0.03630

*Power Data—With Spiked Roll and Spreader Bar

0	0	0.00520	0.00000	0.00520	0.00000	0.00430	0.00000
2	2.489	0.00661	0.00606	0.01267	0.00575	0.00620	0.00517
4	4.979	0.00802	0.01210	0.02012	0.01150	0.00807	0.01035
6	7.469	0.00943	0.01820	0.02763	0.01730	0.01000	0.01550
8	9.958	0.01084	0.02420	0.03504	0.02300	0.01190	0.02070
10	12.611	0.01224	0.03030	0.04274	0.02880	0.01395	0.02600
12	14.938	0.01366	0.03640	0.05006	0.03460	0.01560	0.03120
14	17.429	0.01506	0.04240	0.05746	0.04030	0.01750	0.03630

* Power data is horsepower per inch width per 100 feet per minute except main generator which is kw.
** Tension is in pounds per inch width.

Figure 8. Adjustable generator voltage winder drive with regenerative braking tension control. Two 75-horsepower 1,750-rpm 230-volt driving motors. 50–60-horsepower 250–1,000-rpm 230-volt braking generator

As an illustration we may consider a modern winder of 228-inch width designed to operate at 3,000 feet per minute on kraft papers up to 150 pounds per ream.

The equipment consists of two 125-horsepower motors on the winding drums, one 125-horsepower 185/945-rpm braking generator, and a 60-kw motor generator set with the necessary booster, constant-current regulator, and control.

The winding drums are 20 inches in diameter, the rider roll and guide rolls are $13^{7}/_{8}$ inches in diameter, and the unwinding roll is 65 inches in diameter, wound on a $13^{7}/_{8}$-inch spool.

At any given operating speed, the speed of the braking generator must vary over a range of 4.7 to 1 and as the unwinding roll decreases in size the winding roll increases as shown in figure 4 with a consequent decrease in WR^2 of the unwinding roll and an increase in WR^2 of the winding roll. In many instances the operation is such that 30- or 32-inch finished rolls are the maximum size and four of these may be wound from a 65-inch roll of paper. The operation is, therefore, intermittent with frequent starting and stopping, and, in addition to the friction and tension load the motors must accelerate this heavy inertia from standstill to top speed in about 20 seconds.

The unwinding roll, instead of being driven, is held back by the braking generator to maintain proper tension in the sheet. During accelerating this tension is composed of two elements, the pull caused by the braking generator and the pull required to overcome the inertia of the roll. Therefore, to maintain a constant tension during acceleration, the tension caused by the braking generator must be reduced by an amount equal to the pull required to overcome the inertia.

To simplify the problem involved we may consider all of these heavy inertias as so much weight concentrated at the periphery of the roll of paper as indicated in figure 5 and calculate the power required to accelerate this weight in the required time.

Curve *A* and *C* figure 5 represents a single large winding roll while curves *B* and *D* represent four 32-inch-diameter rolls wound from one 65-inch roll of paper.

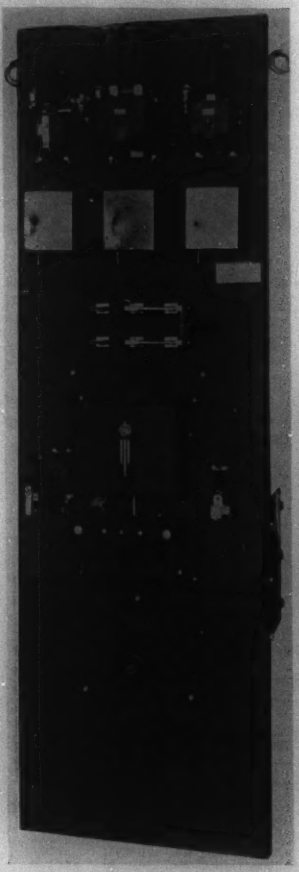


Figure 9. Main control panel for adjustable generator voltage winder drive

The tabulated data in table I show the equivalent weight of the complete winder together with the force and horsepower torque required to accelerate it in 20 seconds for various diameters of the unwinding roll. It also shows the equivalent weight of the unwinding roll together with the force and horsepower torque required to accelerate it.

The average horsepower torque required to accelerate the complete winder is 205.7 while the average horsepower torque required to accelerate the unwinding roll is 38; therefore, the tension held by the braking generator should be decreased by a corresponding amount to maintain a constant sheet tension during this operation. This is automatically taken care of by the regulator through the system of wiring connections.

When operating at top speed (3,000 feet per minute) the input to the driving motors resulting from friction and sheet tension is 212 horsepower while the power returned to the line from the braking generator is 137 horsepower leaving 75 horsepower to be supplied by the motor generator set. During acceleration the input to the motors (in terms of maximum speed) is 435 horsepower but because of the easing off in tension held by the braking generator, only 101 horsepower is returned to the line, leaving the motor generator set to supply 334 horsepower or 250 kw during this short period of time.

Figure 10. Auxiliary control panel for adjustable generator voltage winder drive

Dynamic Braking

Quick stopping is very important, especially on high-speed winders, and provision is made for electrical braking

Comparison of Methods of Stopping Squirrel-Cage Induction Motors

By W. I. BENDZ

APPLICATION engineers frequently encounter the problem of choosing between the several available methods employed to stop a squirrel-cage induction motor quickly. To the best of the writer's knowledge, little has been done to present data in such a way as to make it useful to draw direct comparisons between these schemes, discuss the advantages of each, and aid in the choice of the method best suited to a particular application. Such is the purpose of this paper.

Paper number 38-50, recommended by the AIEE committee on general power applications, and presented at the AIEE North Eastern District meeting, Lenox, Mass., May 18-20, 1938. Manuscript submitted February 17, 1938; made available for preprinting April 23, 1938.

W. I. Bendz is in the engineering division of the Westinghouse Electric and Manufacturing Company, Boston, Mass.

The schemes most commonly encountered in industrial equipment are: (1) Braking applied by a magnetically released, spring-set friction brake either of the shoe or disk type, or (2) Plugging, using a reversing magnetic controller usually in combination with a "plugging" or "zero-speed" switch driven from the motor shaft, (3) A scheme which is rapidly gaining favor for industrial application is the application of direct current to one or more of the motor stator phases and thereby stop the motor by what has been commonly referred to as "dynamic braking." (4) A fourth scheme discussed herewith is dynamic braking using a capacitor and resistor in which case the motor functions as an induction generator. Occasionally, an application warrants combining two braking schemes to obtain a desired function of a drive. Some suggestions in regard to this are also discussed.

Magnetically Operated Friction Brake

Probably the oldest and certainly the most common method of stopping ac-motors is by means of a spring-set magnetically released friction brake. The coil of the brake magnet is usually connected directly across two of the motor terminals so that the brake is energized

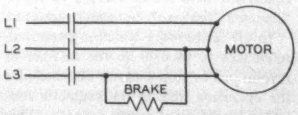


Figure 1A. Brake coil connected across motor leads

(released) whenever power is applied to the motor and the brake coil de-energized (brake set) when power is disconnected from the motor. Earlier construction was such that the brake frame was separate from the motor and the two units had to be properly aligned. Co-ordinated designs now usually include the

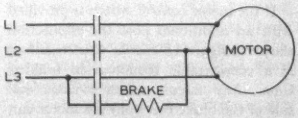


Figure 1B. Brake coil connected with separate circuit

brake frame with the rear motor bracket and mount the brake wheel directly on a rear extension of the motor shaft. This design has been used for many years although a recent modification has been the introduction of disk-type brakes rather than shoe brakes. The disk brakes are neat in appearance and completely enclose all rotating parts. Since there is no difference in the function of either type of brake, the comments which follow apply equally well in both cases.

The application of "thrustor" brakes has been omitted from this paper for the reason that the writer is herein mostly on both the winder motors and unwinding roll. This feature has a considerable bearing on the selection of motor capacities where light-weight papers are involved because the inertia of the winder and the roll of paper are likely to have a greater bearing on the motor capacity than the sheet tension under these conditions.

Power Requirements

The power required to drive a winder is made up of friction load and sheet tension and while there is some slight variation in the friction load of different winders, it is permissible to assume an average friction load and calculate the power requirements on the basis of sheet tension, assuming that the spreader bar or spiked roll or both are used in the operation. Such power data have been calculated and are herewith submitted in table II and figure 6.

An attempt has also been made to indicate the approximate tension required for sheets of various weights, based on recent experience and tests on winders now in operation. This is indicated in the curve, figure 6, and while there are scant data on this subject, and some difference of opinion, it will serve as a guide to the trade in selecting the sheet tension. The capacity of the equipment, however, is definitely determined by the sheet tension and equipments for this service should be so specified.

Conclusion

The big advantage in this type of drive is in maintaining constant sheet tension at any desired value and correctly winding rolls of uniform density. The load distribution between the motors and the sheet tension is indicated at all times and fast smooth acceleration and deceleration are available.

Regenerated power, while not of primary importance, does nevertheless make available power which otherwise must be dissipated as heat, and permits of using much smaller motor generator sets than would otherwise be possible. For example, a 228-inch winder operating at 3,000 feet per minute on a 300-pound kraft sheet would require two 200-horsepower driving motors, a 100-kw motor generator set and a 225-horsepower braking generator, which, on the basis of 50 per cent operating time would save approximately 810,000 horsepower-hours per year; power which might be used to good advantage elsewhere in a mill.

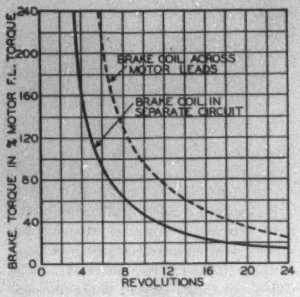


Figure 2. Comparison of brake-coil connections

concerned with motor ratings to which "thrustor" brakes are not usually adapted.

In all of the data which is presented, references to time or to the number of revolutions to stop a motor also includes the operating time of the magnetic contactor used for the motor control. This fact should be remembered when examining the shape of curves plotted against time or distance to stop.

The usual method of connecting a brake of this type is to wire the magnet coil directly across two of the motor leads, as illustrated in figure 1*A*.

The motor control disconnects the motor circuit and de-energizes the brake coil as well. This method of connecting the brake is simple and inexpensive since the brake is always beside the motor and the conduit wiring reduced to a minimum.

If the motor control switch is provided with an additional pole the connection shown in figure 1*B* can be used resulting in a considerable reduction in braking time. Any circuit which isolates one side of the brake coil from the motor can be used equally as well. The purpose of this connection is to completely de-energize the brake magnet at the same instant as the motor is disconnected from the line in order to bring about immediate application of the braking force.

The results of a test to show a comparison between these two connections, taken on the same motor and brake are plotted in figure 2. The dotted curve is the result of connecting the brake coil directly across the motor terminals as in figure 1*A* while the solid curve is the plot of performance when employing the separate brake coil connection shown in figure 1*B*. It is apparent that the difference in revolutions traversed during deceleration for the two schemes is greater at the lower value of braking torque. The explanation rests in the fact that the reduction in braking torque was obtained by weakening the spring of the brake. As the spring was made weaker the voltage appearing across the brake coil as a result of it being connected across the motor terminals caused increasing delay in the application of the brake, when this method of control was used.

The results shown in figure 2 were obtained on a three-horsepower six-pole frame *W*-254 motor equipped with a standard solenoid brake. The same tests were made on four- and eight-pole motors, both two and five horsepower. Similar results were obtained and in general it can be said that the difference

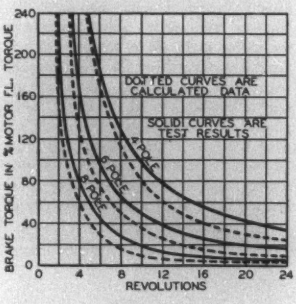


Figure 3. Comparison of calculated and test performance

between the two schemes is less for eight-pole motors and greater for four-pole motors. This is as would be expected since the higher speed motors will turn a larger number of revolutions for a given unit of time delay for the application of the brake.

The result of these tests brings about the conclusion that whenever maximum braking effect is required it is worth while to open the brake-coil circuit by means of a separate contact.

Figure 3 shows a plot of braking torque against revolutions to bring the motor to a stop for four-, six-, and eight-pole three-horsepower motors with the brake coil opened by a separate contact as in figure 1*B*. These curves may be considered as typical for motors of any horsepower rating but individual cases will depart from the performance illustrated due to variation in the ratio of torque to WR^2 for different motors. For this reason it seemed advisable to compare actual performance with theoretical calculated values from which one may consider the expected performance of any similar motor and brake.

The results of calculated performance for the motors tested in figure 3 are shown by the dotted curves. These were calculated from the braking torque, motor WR^2, and adding a factor of one-tenth second for the control and brake to operate. Tests showed that the average control and brake operated in about six cycles when the brake was adjusted for its maximum rating. A somewhat longer time was required when the brake spring (and torque) was decreased but this variation was neglected for the purpose of simplifying the discussion.

The importance of the curves plotted in figure 3 is that the performance as calculated from braking torque, motor WR^2, and control operating time checks reasonably well with actual operating conditions. Furthermore, it can be concluded that there is little to be gained by applying a brake rated much more than 100 per cent of the motor full-load torque and certainly no reason to exceed 200 per cent torque. This statement is true only when the WR^2 of the connected load is small compared with the motor. Choice of the proper brake must take this into account.

Figure 4 shows a plot of braking torque against time to stop the motor for six- and eight-pole three-horsepower motors. While other ratings were tested the results were not included in the figure because of the confusion of curves. As was brought out during the discussion of figure 3, calculated performance is reasonably accurate from which other ratings could be added to figure 4.

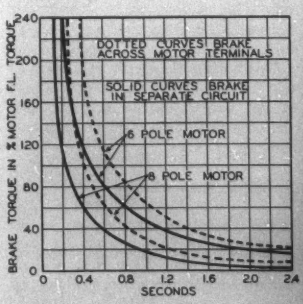


Figure 4. Comparison of brake-coil connections

The solid curves of figure 4 are the results obtained when using the separate brake coil connection shown in figure 1*B* and the dotted curves correspond to the connection of figure 1*A*.

To summarize the application of magnetic brakes the following conclusions may be drawn:

1. When the maximum braking effect is required it is worth while to select the control to provide the separate brake-coil circuit as shown in figure 1*B*.

2. Except in cases where the WR^2 of the connected load is a considerable portion of or greater than the motor inertia, there is not much gained by selecting a brake rated more than 100 per cent of the motor full load torque; no practical gain by exceeding 200 per cent torque.

3. Theoretical performance calculated by the following formulas are sufficiently close for most practical applications:

$$\text{Time to stop} = \frac{WR^2 \times \text{rpm}}{308 \times \text{brake torque}} + 0.1$$

$$\text{Revolutions to stop} = \frac{WR^2 \times (\text{rpm})^2}{3.70 \times \text{brake torque}} \times 10^{-4}$$

Where

Time is in seconds
Brake torque is in pound-feet
WR^2 is in pound-feet^2

Plugging Squirrel Cage-Motors

Plugging control to stop squirrel-cage motors is becoming more widely used for many kinds of industial applications. The reasons for this are (1) the increased capacity of feeder systems, thereby more universally eliminating the objection to

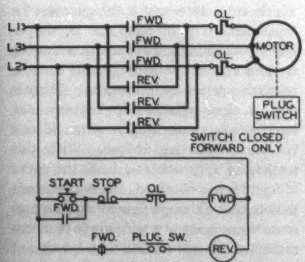


Figure 5. Schematic diagram of full-voltage plugging control

the relatively high line current required for effective stopping, (2) the improvement in motor design to electrically and mechanically withstand the stress during plugging, and (3) the availability of proper and reliable control apparatus for plugging service.

The majority of plugging applications are those for which the motor is connected across the power lines at full voltage by means of a pair of reversing contactors. A typical magnetic push-button control for this purpose is shown in figure 5.

A plugging switch, frequently referred to as a zero-speed switch, is driven from the motor shaft or from machine shafting coupled to the motor. This type of switch is designed so that its contacts close only due to rotation in one direction and are therefore open at zero speed or reverse rotation. Inspection of the diagram shows how the normally closed interlock of the "forward" contactor prevents the "reverse" contactor from being energized while the motor is running forward. As soon as the "stop"

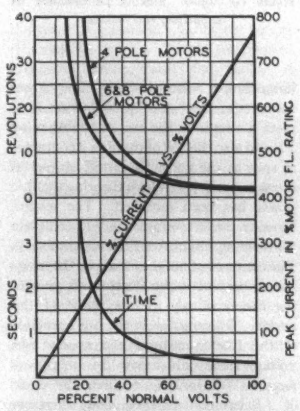


Figure 6. Performance by reduced-voltage plugging

push button is depressed the circuit to the "reverse" contactor is completed through the "forward" interlock and plugging switch. The motor is then plugged to rest and at zero speed or upon slight reversal the plugging switch opens its contacts and de-energizes the "reverse" contactor.

Control is also available for reversing service in which case the plugging switch has two sets of contacts, one of which is closed by the forward rotation and the other by backward rotation. The motor is plugged to rest when the "stop" push button is depressed, no matter in which direction the motor may be running.

Figure 6 shows a plot of time and also the number of revolutions to stop against motor voltage in per cent of the normal rating. The voltage referred to is the value existing across the motor terminals at the instant of first starting to plug. The reduction in voltage below normal is obtained by connecting equal resistors in

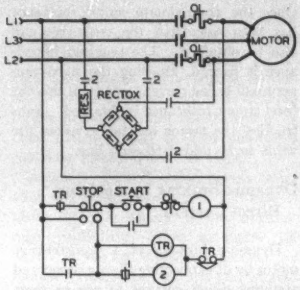


Figure 7. Schematic diagram of d-c braking control using copper-oxide rectifier

the three motor lines. Therefore, the abscissa and the right-hand ordinate are values occurring at the same instant.

This figure also includes a plot of peak current required to plug a motor at any given per cent of normal voltage. By use of these curves the peak line current required to produce a desired rate of deceleration can be determined.

The data from which figure 6 was prepared were obtained by testing a number of motors between one-quarter and ten horsepower, four-, six- and eight- pole. Although the curves of this figure represent average values for this wide range of ratings it is important to note that individual cases did not depart from the average curve more than 10 per cent in regard to revolutions or time plotted against per cent voltage. However, there was a somewhat wider variation when considering the peak current drawn at 100 per cent normal voltage and this factor should not be overlooked when applying this data.

It is important to note that the results shown refer to a constant line voltage. If the line potential is decreased during the plugging interval the performance is changed radically. As an example, a test was made on one motor, holding the line voltage constant and adjusting series resistors to limit the plugging current to 400 per cent which resulted in 5.0 revolutions to stop the motor. The same motor was connected across a generator and feeder system of such poor regulation that the plugging current was also 400 per cent but without any series resistors. In the latter case the motor required 8.0 revolutions to stop or an increase of 60 per cent.

The amount of resistance to connect in series with the motor to limit the plugging current to any desired value can readily be calculated from the motor locked-rotor current and power factor.

Once the approximate motor reactance has been calculated the resistance can also be obtained. The required impedance is figured, knowing the maximum permissible line current and from this the total circuit resistance is obtained. Subtracting the motor resistance leaves the value to be added to each line.

Dynamic Braking by Applying Direct Current

Dynamic braking of a squirrel-cage motor by disconnecting the a-c power and applying direct current to one or more stator phases is not a new scheme but has not been widely used to date. Perhaps lack of sufficient application data and inadequacy of a source of direct current are the major factors limiting its use. There are many applications for motors three horsepower and below, particularly on machine tools, that require smooth braking and in many cases a Rectox copper-oxide rectifier is well suited to supply the necessary direct current.

One suggested wiring diagram for a unit consisting of control and Rectox is shown in figure 7. This scheme includes a time delay relay to disconnect the rectifier at the end of the braking period which is a feature that is not required in all cases.

Referring to the diagram, if the "start" push button is depressed the number 1 line contactor is energized and its interlock contact bridges the "start" push button. The motor is then running, energized by the a-c power line. If the "stop" push button is depressed the circuit to number 1 contactor is broken and the a-c power is immediately disconnected. The lower contacts of the "stop" push button complete a circuit to the coil of timing relay *TR* and also the coil of number 2 contactor as soon as the normally closed contact of number 1 seals, thereby indicating that a-c power has been removed. The instantaneous make contacts of *TR* complete the holding circuit to *TR* and number 2. The contacts of number 2 apply the alternating current to the Rectox and connect the d-c terminals to one phase of the motor. The resistor in the a-c terminals of the Rectox reduces the applied a-c voltage since only a low d-c voltage is required for braking. When the cycle of *TR* expires, its time delay contacts open thereby dropping out number 2 contactor and resetting *TR*. This, of course, disconnects the rectifier but the cycle of *TR* should be made long enough to be certain that the motor has come to rest.

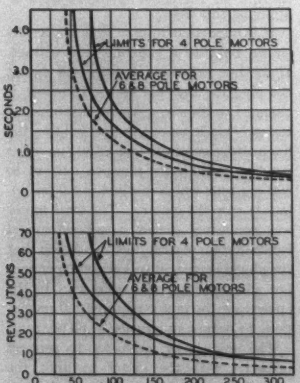


Figure 8. Performance by d-c braking

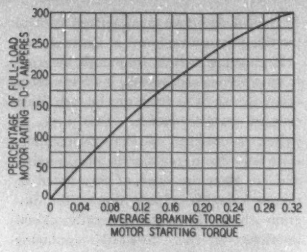


Figure 9. Required direct current for braking can be calculated by using this curve

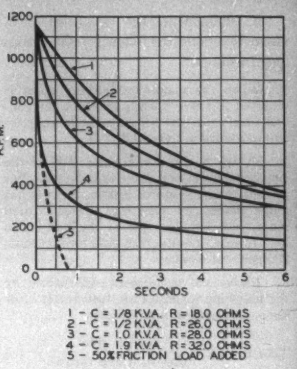


Figure 10 (right). Braking performance by capacitors and resistors

If a source of d-c power were available the Rectox rectifier could be omitted and the same control used except for the details of connecting number 2 contactor between the d-c line and the motor terminals. The timing relay would be required because in order to obtain effective braking a value of direct current must be applied which would overheat the motor if allowed to continually circulate while at rest.

The time and also number of revolutions required to stop a motor are plotted against direct current in per cent of motor full-load rating in figure 8. A large number of tests were made on motors ranging from one-quarter to ten horsepower, four, six, and eight poles. In studying the results of tests made on these ratings it was found that motors of like number of poles performed very similarly, particularly on the part of the curve having the most practical use. The minimum and maximum performance for the group of four-pole motors is plotted and designated as limits in figure 8. Limits were shown for four-pole motors only and the average for six- and eight-pole motors in order to eliminate unwarranted confusion of the curves.

The results shown by figure 8 pertain to motors not connected to a load and, of course, represent a wide range of windings and rotor inertia. In order to present data which could be used to predict the time or revolutions to stop a motor connected to a load (of which the friction and WR^2 is known) the variable factors which enter into motor design must be separated. The problem can be simplified by obtaining the average decelerating or braking torque throughout the decelerating period by test results. There is also a close relationship between the braking torque per ampere obtained and the motor starting torque. With this method of approach as a basis the curve of figure 9 was obtained. It is significant to note that although figure 9 again represents the average of a wide range of motor ratings there was no individual design of standard squirrel-cage motor that departed from the average curve more than ten per cent, which is a sufficiently close check for practical applications.

Figure 9 can be used to calculate the required direct current to obtain the desired braking effect by knowing, (1) the friction and WR^2 of the connected load, (2) the WR^2 and starting torque of the motor and preferably, (3) the stator resistance of the motor. The average decelerating torque to stop the motor and connected load is readily calculated from the formula given at the close of the section on friction brakes. Knowing the motor starting torque the ratio of

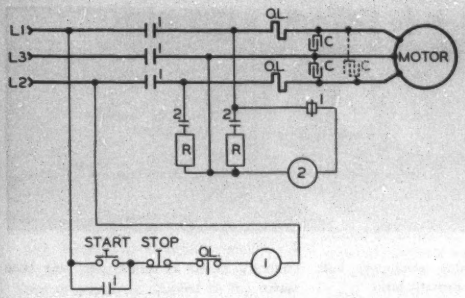


Figure 11. Schematic diagram of control for capacitor and resistor braking

average braking torque divided by motor starting torque can be obtained and figure 9 applied to get the direct current required for effective braking. If the motor stator ohmic resistance is known the resultant direct voltage can be figured and the details as to the required source of direct current easily follow.

With the exception of fractional horsepower ratings it is sufficiently accurate to assume that the motor d-c resistance is six per cent of the motor rated voltage divided by its full-load current. Fractional horsepower windings vary considerably and may depart from this rule by so much as 500 per cent. Consequently, care must be used to obtain exact winding data before proceeding with each application.

From inspection of the data presented in figure 8 and comparing this performance with figures 3, 4, and 6, it can readily be seen that it is impossible to stop a motor as quickly by means of d-c braking as by means of full voltage plugging, but the former does approach the effectiveness of a magnetic brake.

While test data show that maximum deceleration is not obtained until the direct current is increased to about 350 per cent of the motor rating, experience has shown that 250 per cent is sufficient in most cases and that the difference in braking effectiveness between these values cannot be noticed without equipment set up to make accurate measurements. There are numerous applications where satisfactory braking can be obtained by using direct current of only 150 per cent of the motor rating.

This scheme of stopping a motor is commonly referred to as "dynamic braking" but the term is not strictly true and it is not at all similar to dynamic braking of a d-c motor. While there is a decrease in braking torque as the speed is reduced, it does not fall to zero and a definite braking torque is applied with the rotor at standstill. Sufficient torque is available at low speed to prevent excessive coasting and the motor is stopped smoothly without the violent shock characteristic of a magnetic brake in particular.

Dynamic Braking, Using Capacitors and Resistors

Any induction motor will function as an induction generator provided it is operated in parallel with apparatus that will supply a leading power factor load since this is the only way by which an induction machine can be excited. Usually, synchronous machines supply the leading power factor but capacitors meet the requirement equally well if connected across the terminals of the machine.

While this method of stopping a motor does not possess many practical advantages it is sufficiently interesting to deserve brief mention.

Either two single-phase or one three-phase capacitor unit may be connected across the motor. The number 1 contactor starts the motor by depressing the "start" push button. The number 2 contactor connects the resistors across the motor terminals when the "stop" button is depressed. The coil of number 2 contactor is chosen to hold number 2 contacts closed to as low a voltage as possible. Since there is very little braking torque below one-third speed there is no point in attempting to hold number 2 contactor closed below this value.

A family of deceleration curves taken with a 2-horsepower 6-pole 220-volt 3-phase 60-cycle frame *W*-225 squirrel-cage motor are shown in figure 10. These curves are motor revolutions per minute plotted against time and therein differ from the type of curves so far presented in this paper.

Because of the inherent characteristic of dynamic braking to become less effective as the speed decreases this method of stopping a motor is useless if the motor is not coupled to a load having some friction. The dotted curve of figure 10 shows how the lower curve (C = 1.9 kva, R = 32 ohms) would be changed if the motor were connected to a drive having a frictional load equal to 50 per cent of the motor full-load torque rating. In this case the motor is brought to rest in about three-fourths second.

The only possibility for a practical application of this method would be when capacitors would be desirable for power-factor correction. For instance, a capacitor value sufficient to produce reasonably effective braking would result in a circuit power factor of approximately 35 per cent leading when the motor operated at about full load.

Special Applications

Examples of a few unusual applications are given below for the purpose of illustrating factors leading to the choice of one or more methods for braking a motor.

The diagram shown in figure 12 is a drive for a machine in which it was desired

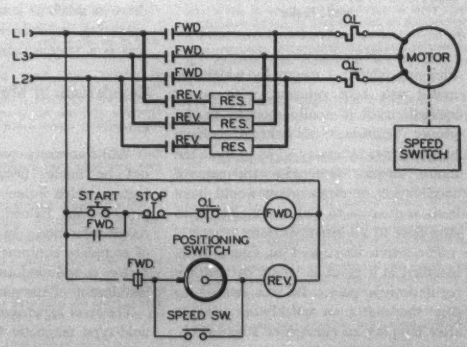


Figure 12. Schematic diagram of special reduced-voltage control

to stop the motor in a given position of a rotating shaft. Reduced voltage plugging was chosen for the application. The positioning switch was direct connected to the shaft to be positioned. Its design was such that a circuit is closed through the switch except for a few degrees of rotation. The speed switch is a centrifugal switch driven from the motor and its contacts are closed from normal down to about 15 per cent speed. Below this speed its contacts are open. The stopping function of this drive is to plug the motor by reduced voltage until the speed decreases to 15 per cent. Below this speed the motor is plugged through the positioning switch until the "dead" zone of the switch is reached. Power is then disconnected and the motor may or may not coast to a stop within the desired zone. If it coasts until the switch recloses the motor is energized through the resistors to rotate the shaft until it again reaches the "dead" zone of the positioning switch.

Reduced voltage plugging was selected for this scheme for two reasons: (1)

Figure 13. Application of oversized magnetic brake

Plugging offered a means by which the motor was kept rotating, with power applied, until it finally stopped in the proper position; (2) reduced voltage plugging was necessary so as to limit the motor torque. Otherwise, the rate of acceleration or deceleration would have been so great as to make it impossible to stop close to a desired position.

The drive illustrated in figure 13 is installed in a plant in which the voltage regulation is poor. It was desired to stop the motor as quickly as possible after tripping an emergency stop switch.

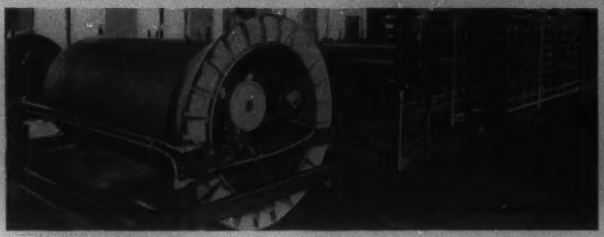


Figure 14. Application employing both plugging and magnetic brake

Poor voltage regulation would have defeated the effectiveness of full-voltage plugging. The problem was solved by using a magnetic brake rated 200 per cent of the motor torque. A two-pole master stop switch was used for the control circuit. One pole was wired into the motor contactor circuit and the other pole directly in the magnetic brake coil circuit. Consequently, when the stop switch was tripped the brake was applied by the time the contactor interrupted the motor line current, with the result that very effective braking was obtained.

Figure 14 shows a drive for which the load has a WR^2 of many times the motor inertia. The drive between the motor and load is by gearing and V belts. Since several times full-load motor torque would be required to produce the desired braking it is obvious that the drive would be stressed severely if a large brake were placed on the motor shaft. It is also true that a brake on the load side would impose a peak load on the drive because of the motor WR^2. The solution chosen was to put a magnetic brake on the load and use full voltage plugging on the motor. The brake was applied so as to make the rate of deceleration of the load approximately match the motor and thereby reduce the stress on the drive as much as possible. Considerable operating experience has proved that this is a very satisfactory scheme.

Comparison of Methods

Cost

While accurate cost comparisons cannot be made because of the many factors which influence the required apparatus, the following may serve as a rough reference. In each case the cost of complete equipment, exclusive of the motor, is included and allowance for the installation of the parts is made.

The least expensive method is a solenoid-type magnetic brake and is consequently taken as a 100 per cent base price.

Full-voltage plugging can usually be installed for about 135 per cent of the brake cost. Reduced voltage plugging will cost about 200 per cent.

Dynamic braking with direct current including a Rectox rectifier will be between 150 per cent and 250 per cent of the brake cost depending upon the duty cycle. If a source of direct current is available and the Rectox therefore omitted, the cost of this scheme can be reduced to about 125 per cent.

Dynamic braking using capacitors and resistors will be about 250 per cent for 220 volts and 200 per cent for 440 or 550 volts.

Magnetic Brakes

Advantages. The magnetic brake is the least expensive scheme to install and while it is not the fastest method for stopping a motor it is second in this choice. No power is taken from the line during the braking period and consequently braking is independent of voltage failure.

Disadvantages. Frequently there is not sufficient space in which to mount a magnetic brake. On applications that start and stop frequently a certain amount of maintenance is always necessary. Furthermore, the person adjusting the brake must be skilled in this or else the brake operation will not be satisfactory. There is a continued consumption of power from the a-c line while the motor is running. If it is desired to manually rotate the motor when power is disconnected special arrangements must be made to either electrically or mechanically release the brake. The torque of a friction brake increases considerably at very low speed which results in a rather violent shock as the motor is brought to rest. For some applications this may be a disadvantage.

Plugging

Advantages. Full-voltage plugging will stop a motor quicker than any other

method provided the power supply is adequate. This scheme is not very much more expensive than a magnetic brake and requires only a normal amount of maintenance. Reduced voltage plugging is a flexible method in that the rate of deceleration may be readily adjusted after installation.

Disadvantages. Plugging, even at reduced voltage, requires more than the motor full-load current taken from the line. If voltage fails the motor will coast instead of stopping quickly. A plugging switch must be mounted, driven from or otherwise coupled to the motor shaft and properly adjusted. Special care in the choice of apparatus must be considered if the application disallows a possibility of the motor rotating slightly in the reverse direction.

D-C Braking

Advantages. This method of stopping a motor does not require any apparatus mechanically coupled to the motor shaft nor is any maintenance required (other than is common to control apparatus). Because of this it is particularly useful on applications subject to frequent starting and stopping. The motor cannot run backwards as may occur if plugging is used and the switch improperly adjusted. The motor is free to be rotated manually at the termination of the braking period and the braking is particularly smooth. If a separate source of power is available braking will be independent of failure of the a-c supply. The separate source may be direct current or another a-c supply independent of the main a-c lines.

Disadvantages. The chief disadvantages of this scheme is its cost relative to a magnetic brake. While this scheme ranks third in its ability to stop a motor most quickly, it is often adequate for a large majority of applications. There can be no braking torque when the main a-c supply fails unless a separate source of power is available from which braking may be obtained.

Dynamic Braking With Capacitors

Advantages. This method offers the advantage of power factor correction while the motor is running and braking is independent of voltage failure of the supply line. Maintenance would be less than for any other scheme of braking the motor.

Disadvantages. Unfortunately, this scheme is a poor fourth in braking effectiveness and at the same time is about the most expensive. Consequently, it is not economically attractive as a means for braking an a-c motor.

The Application of Capacitors for Power-Factor Correction in Industrial Plants

By C. E. H. von SOTHEN

WHILE a paper on this subject before an AIEE meeting seems rather superfluous, perhaps a review of some of the facts to be considered in the application of capacitors to industrial loads will bring out a discussion that will be beneficial to all.

Greater interest has been shown in this subject during the past few years, both because of the wider application of power rates having some form of power-factor clause, and because of the reduction in power costs to the industrial customer, if the power factor is corrected. The utility companies generally have urged those customers who may benefit by power factor correction, to install the necessary equipment and in some cases have recommended the amount of corrective capacity to meet the conditions existing. The manufacturing companies have, of course, also made a great many surveys, each case being worked up individually to determine the amount of correction which will provide greatest return on investment.

A capacitor or static condenser consists principally of metal foil and paper insulation in a metal container and generally assembled in a rack or housing for indoor or outdoor service.

Data Required

The data required to make proper ap-

Paper number 38-51, recommended by the AIEE committee on general power applications and presented at the AIEE North Eastern District meeting, Lenox, Mass., May 18–20, 1938. Manuscript submitted February 14, 1938; made available for preprinting April 22, 1938.

C. E. H. VON SOTHEN is local office engineer with the General Electric Company at Syracuse, N. Y.

Conclusion

In conclusion, the following suggestions should aid in selecting the best method of braking:

1. If the most important consideration is stopping the motor as quickly as possible:

(*a*) Determine if the source of supply is capable of delivering at least six times the motor full load current without dropping the voltage at the terminals of the motor more than five per cent. If the supply is adequate use a full voltage plugging controller.

(*b*) If the supply is inadequate use a magnetic brake rated 150 per cent to 200 per cent of the motor full-load torque and a control designed to open the brake coil separately from the motor winding.

2. If the most important consideration is availability of normal braking even with the failure of the main a-c supply system:

(*a*) A magnetic brake is usually employed in such cases.

(*b*) Dynamic braking using direct current is equally as good as a magnetic brake if a separate source of direct current is available. It may be worthy of consideration if the separate source is alternating current in which case a rectifier would be used.

(*c*) Dynamic braking using capacitors would meet the requirements providing a very quick stop were not necessary.

3. If the most important consideration is ability to withstand frequent operation without undue maintenance:

(*a*) A magnetic brake will require the largest amount of maintenance of any method of braking.

(*b*) Dynamic braking using direct current is the most attractive scheme both from the point of view of freedom from maintenance and least shock to the drive.

(*c*) Full voltage plugging can be used if the power supply is adequate and the motor applied so as to withstand the heating that results from frequent plugging. Some maintenance of the plugging switch and magnetic contactors will be required.

4. If the most important consideration is a smooth stop without shock to the drive:

(*a*) Dynamic braking using direct current is highly recommended for this application.

(*b*) Dynamic braking using capacitors would produce a smooth stop and may possibly deserve consideration.

5. If the most important consideration is assurance that the motor will not rotate backward:

(*a*) A magnetic brake or d-c braking are equally good in this respect as neither can result in backward rotation.

(*b*) While it would not be correct to state that plugging could not be used for such an application, it is true that this method is more subject to reversal than any other and extreme care should be used in the selection and adjustment of the plugging switch.

6. If the most important consideration is freedom of the motor to be rotated manually without the application of power:

(*a*) Dynamic braking using direct current presents no complications for such an application.

(*b*) Plugging can be used with some limitations. A friction type of plugging switch cannot be used, because manual rotation of the motor will cause the plugging switch to energize the control and apply power to the motor (unless a special control is designed to prevent this). A centrifugal type of plugging switch can be applied if the speed when rotated manually is below the minimum point at which the switch will close its contacts.

(*c*) Dynamic braking using capacitors would be applicable and may possibly deserve consideration.

plication generally should include the following:

1. Magnitude and power factor of the load, both maximum and average.

2. Character of the load; constant or variable?

3. Statement of power rate.

4. Is metering on high or low side of step-down transformers?

5. Are the feeders within the plant of ample capacity or are some overloaded?

6. Rating of the transformers. Are they owned by the utility company or by the industrial company?

7. Will an indoor or outdoor capacitor equipment be more satisfactory?

8. Voltage of circuit (normal and maximum).

9. Is any additional load being considered?

10. What are the atmospheric conditions at proposed capacitor location? Are they normal or are dust, corrosive fumes, and so forth, present?

11. What is the maximum ambient temperature?

Standard Types Available

It might be well to discuss briefly the various types of capacitor equipments available for industrial applications. There are four general types for use as follows:

1. The enclosed dust-tight capacitor unit for connection to individual motors or small groups of motors rated 230, 460, or 575 volts. These may also be combined in racks to make up a dust-tight equipment.

2. The small rack capacitor for indoor installation, for use at 230, 460, 575, 2,300, 4,000, and 4,600 volts, at one or several points in a plant. This design fulfills practically all industrial-plant requirements and affords maximum economy with reference to reduction of line loss.

3. The pole-type outdoor capacitor, corresponding to the indoor small rack for 2,300, 4,000, and 4,600 volts. This can be either mounted on a pole or bolted to a foundation.

4. The large rack equipment for either indoor or outdoor installation, for improving power factor of a large block of power at one point, on circuits of from 230 to 6,900 volts.

There have been a few installations of automatically controlled capacitors to maintain approximately constant power factor, reactive kilovolt-amperes, or current of some predetermined value. These depend upon some form of master relay which opens or closes oil circuit breakers or contactors controlling several blocks of capacity. The advantage is that a higher average value can be held without going too far leading at light loads. Whether such an equipment will prove economical depends, as usual, upon the power contract.

The foregoing covers the types available. Now how should they be applied?

The manner in which the problem is approached to meet conditions imposed by various classes of rates may be illustrated best by a few typical examples from various parts of the country.

Calculations

Case I

The power contract contains the following rates and provisions:

Rate: (per month)
Demand charge:
$1.25 net, per kilowatt of maximum demand for the first 500 kilowatts of demand
$1.00 net, per kilowatt of maximum demand for all over 500 kilowatts of demand
plus
Energy charge:
1.5¢ net, per kilowatt-hour for the first 10,000 kilowatt-hours
0.9¢ net, per kilowatt-hour for all over 10,000 kilowatt-hours
Minimum charge:
The demand charge.
Special provision:

(*a*) When customer's power factor is less than 80 per cent or more than 90 per cent, the billing demand shall be increased or decreased in the ratio that 85 per cent bears to the actual power factor. The power factor shall be determined monthly by computation from the registration of active and reactive watt-hour meters.

In this case power was supplied at 6,900 volts, 3 phase, 60 cycles. There was ample transformer capacity and none of the 230-volt feeders was overloaded. Therefore only primary capacitors were considered, for installation in the main switch-board room.

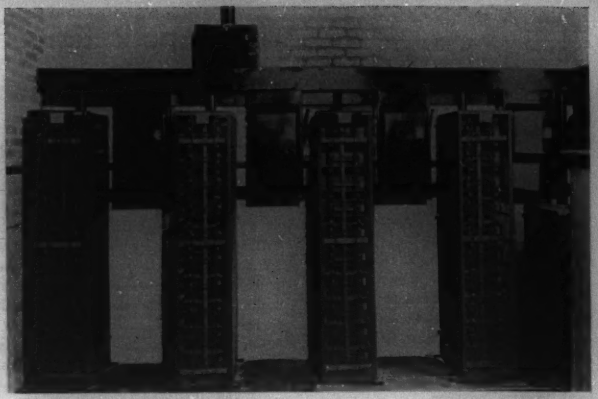


Figure 1. Four 100-kva and one 60-kva 3-phase 60-cycle 460-volt indoor small rack capacitors

The power bills for one year were used as a basis for calculations. A typical month showed the following:

Actual demand	1,056 kw
Power factor	60 per cent
Reactive kilovolt-ampere hours	277,600
Kilowatt-hours	208,800

All figures were based on a rack large enough for 540 kva, but containing various numbers of units as an initial installation, starting with 495 kva. Indications were that additional capacity would be required in the future.

The 495-kva equipment would have to operate during the month in question only 560 hours to average 100 per cent power factor, but let us say 625 hours. The billed demand would be 85 per cent of 1,056 or 898. The loss on this equipment would not exceed 1.65 kw but say 2 kw which would increase the demand to 900 or a net saving in demand of 156 kw. This at $1.00 per kilowatt amounts to $156 saving in demand charge.

The loss of 1.65 kw for 625 hours at 9 mils amounts to $9.30 or say a net saving in the power bill for the month of $146.

Each month was figured similarly and the total annual saving on the power bill amounted to $1,804. The equipment had a first cost of $5,667 and an installed cost of $6,060. Carrying charges may be taken as nine per cent of $5,667 or $510. (Interest is omitted since the purpose of the calculation is to determine the return on the investment.) The net annual saving is then $1,294 or a return

of 21.3 per cent on the investment of $6,060.

Other sizes were figured and the result was the recommendation of a 540-kva rack containing 360 kva in units. This showed a return 27.8 per cent on an investment of $4,700.

Of course if a 360-kva rack could have been used, the initial cost would have been lower and the return would have been greater.

CASE II

The power rates in this case were as follows:

Demand—First 100 kva	$3.00 per kilovolt-ampere
All in excess	$1.50 per kilovolt-ampere
Energy—First 200 hours use of kilowatt demand per month	$0.007 per kilowatt-hour
All over 200 hours	$0.005 per kilowatt-hour

As the kilovolt-amperes would never be reduced below 100, all savings were at $1.50.

Power was supplied at 13,200 volts and stepped down to 480 volts. As this was a grain mill, dust-tight equipment was required. From billing data for the year 1936 it was found that the average was 611 kva demand, 455 kw, 74.5 per cent power factor, and 408 kva lagging reactive.

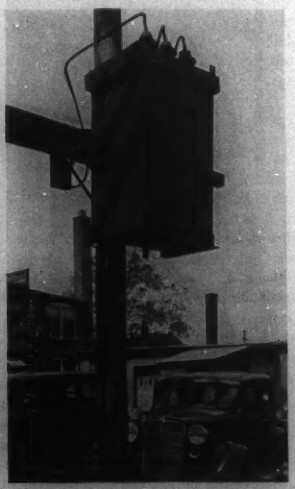


Figure 2. Forty-kva 4,000-volt 3-phase 60-cycle pole-type capacitor

As the corrective kilovolt-amperes of a capacitor varies as the square of the voltage, a 210-kva 460-volt equipment will provide 229 kva leading. This reduces the reactive to 179 and kilovolt-amperes to 489, or a saving of 122 kva per month. For 12 months at $1.50 per kilovolt-ampere, the saving in demand is $2,196. The loss on this equipment would not exceed 0.76 kw which for 16 hours per day and 300 days per year at $0.005 per kilowatt-hour would amount to $18.24 per year. The net saving on the power bill would therefore be $2,177.76 per year.

A 210-kva 460-volt dust-tight capacitor equipment had a first cost of $2,103 and estimated installed cost of $2,313. Carrying charges were taken at nine per cent or $208 so that the net annual saving would be $1,970 which represents a return of 85.1 per cent on the investment of $2,313.

Other sizes were calculated similarly with the results shown in table I.

While the 180-kva equipment shows a greater per cent return, the extra investment for the 210 kva would be paid for in two years. The same might be said for the 240 kva over the 210-kva equipment, but it was found that the 240-kva equipment would correct the power factor to 99 per cent at time of maximum demand for some months, which would mean leading power factor on average loads. The 210-kva equipment was therefore installed.

CASE III

While this case involves a rather small installation, it illustrates another form of power contract which may be of interest.

Monthly Demand (Kilowatts)		Demand Charge (Dollars)
First	10 or less	30.00
Next	15	2.50 per kilowatt
Next	25	2.00 per kilowatt
Next	50	1.50 per kilowatt
Next	1,900	1.25 per kilowatt
Next	2,000	1.00 per kilowatt
All over	4,000	0.90 per kilowatt

Monthly Use (Kilowatt-hours)		Energy Charge (Cents per Kilowatt-hour)
First	1,000	2.5
Next	1,500	2.0
Next	2,500	1.5
Next	5,000	1.0
Next	190,000	0.85
Next	300,000	0.75
All over	500,000	0.65

Special Provisions. The service supplied by the company shall be taken by the consumer whenever possible at an average power factor of not less than 70 per cent lagging. If the service is taken at an average power factor of less than 70 per cent lagging, then the demand for billing purposes, in lieu of the measured demand, shall be taken as the product of the measured demand and the quotient resulting from dividing 70 per cent by the actual average lagging power factor expressed in per cent. If the service is

Figure 3. Three hundred-kva 460-volt 3-phase 60-cycle large rack capacitor

taken at an average power factor of more than 85 per cent lagging, then the demand for billing purposes, in lieu of the measured demand, shall be taken as the product of the measured demand and the quotient resulting from dividing 85 per cent by the actual average lagging power factor expressed in per cent.

The average power factor for the month shall be determined by computation from the registration of an active watt-hour meter and a reactive watt-hour meter. It shall be the quotient resulting from dividing the registration of the active watt-hour meter by the square root of the sum of the square of the registration of the active watt-hour meter and the square of the registration of the reactive watt-hour meter.

As there was a detent or ratchet on the reactive watt-hour meter, nothing could be gained by operating at leading power factor during light-load periods.

In this case the primary voltage was

Table I

Capacitor Rating (Kva)	Corrected Power Factor	First Cost	Installed Cost	Net Annual Saving	Per Cent Return on Investment
150	90	$1,548	$1,703	$1,526	89.5
180	91	1,817	2,000	1,800	90.0
210	93	2,103	2,313	1,971	85.1
240	95.5	2,463	2,709	2,147	79.0

4,000 and plant voltage 230. As several circuits were rather badly overloaded, secondary capacitors, distributed over some of the branch circuits, presented definite advantages over an installation on the primary side. Furthermore, conditions were such that a primary capacitor would have to be installed outdoors, adding to its cost.

Billing for only four months was available, on which to base calculations, but results have indicated the assumptions to be correct. These were as shown in table II.

Table II

Month	Kilowatt-hours	Reactive Kilowatt-hours	Demand Read	Power Factor	Demand Billed	Penalty @ $1.25
August	25,200	38,200	124	55	158	$43.00
September	23,940	35,560	141	56	176	43.75
October	22,540	32,900	121	57	149	35.00
November	21,280	29,120	136	59	161	31.25

The plant was operating 16 hours per day and 5 days per week with the following results:

Month	Average Kilowatts	Average Reactive Kilovolt-amperes	Corrective Kilovolt-amperes Required: For 72 Per Cent Power Factor	Corrective Kilovolt-amperes Required: For 87 Per Cent Power Factor
August	71.5	108.5	39.5	68.0
September	71.3	106	34.0	66.0
October	67.0	98	34.0	60.0
November	60.5	82.8	25.0	49.0

The values of 72 per cent and 87 per cent were taken rather than 70 per cent and 85 per cent to allow some margin for changes in conditions. The first value is necessary to avoid the penalty and the second is required if a bonus is to be earned.

It is evident that a 40-kva capacitor will correct each month to 70 per cent or better. What will be its effect in November?

Forty kva for 22 days and 16 hours per day or 14,100 reactive kilovolt-ampere-hours leading. This leaves a net of 15,020 reactive kilovolt-ampere-hours lagging which combined with 21,280 results in an average power factor of 82 per cent; not sufficiently high to earn the bonus.

To determine the effect of a 70-kva equipment, consideration must be given to the fact that for a few hours each day, the power factor may be leading, and with the "detent" on the meter the result is the same as unity power factor. By checking the active and reactive meters carefully and obtaining a record of demands, it was found that during working hours, the load never dropped below 35 kw at 55 per cent power-factor or 53 reactive kilovolt-amperes. From demand-meter records for the four months it was found the power factor with a 70-kva equipment would be leading for one hour per day in August and September, two hours in October, and three hours in November and it was assumed the leading kilovolt-amperes would be 70 minus 53 or 17 kva. Therefore, the effect would be as follows for August:

$$70 \times 22 \times 16 = 24{,}640 \text{ reactive kva}$$
$$17 \times 22 \times 1 = -380$$
$$24{,}260 \text{ reactive kva}$$

38,200 reactive kva
−24,260

13,940 reactive kva

$$\frac{R}{KW} = \frac{13{,}940}{25{,}200} = 0.554$$

or 87.5 per cent power factor

Similar calculations for the other months gave these results:

September	88.5 per cent
October	91.5 per cent
November	96.5 per cent

The effect of the 40-kva equipment would be to avoid the penalty or a saving of $153 for four months or approximately $459 per year.

This equipment consisting of 8 5-kva 230-volt enclosed units with hangers and with fuses and dischargers would have a first cost of $728 and installed cost of $800. The net annual saving with nine per cent carrying charge would be $393 representing a return of 49.1 per cent on the investment of $800.

With the 70-kva equipment the penalty would be avoided and bonus earned each month. For example in August, the billed demand would be

$$124 \times \frac{85}{87.5} = 121$$

or a saving of 37 kw over the demand as actually billed (158 kw). For September this would be 41 kw, October 36 kw, November 41 kw, at $1.25 per kilowatt these total $193.75 or approximately $581.25 per year.

A total of 14 5-kva 230-volt enclosed units had a first cost of $1,274 and installed cost of $1,400. The net annual saving with nine per cent carrying charge would be $466 or a return of 33.4 per cent on the investment of $1,400.

Because of the greater return from the 40-kva equipment and the fact that conditions were somewhat uncertain, this equipment was recommended with the suggestion that a further study be made at a later date, with the possibility of installing additional units.

Protection

The problem of protecting capacitors and lines is similar to that on any electric system involving a relatively large number of pieces of apparatus fed from a common source. In rack and pole-type equipments the entire group of units is fed through one circuit-interrupting device, which is generally set to trip at twice normal line current. Therefore, many times normal current of an individual unit could flow into a fault within

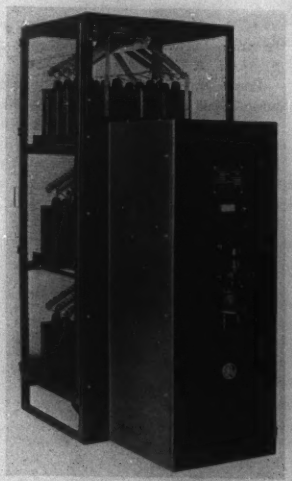


Figure 4. Two hundred forty-kva 4,600-volt 3-phase 60-cycle indoor large rack capacitor

the unit without opening the line circuit breaker. Individual fuses, however, will limit the amount of energy dissipated within a capacitor unit case by quickly clearing the fault and without interrupting power supply to the remainder of the equipment.

When a capacitor is disconnected from the line, electrical energy remains stored within the unit. All types of equipment must therefore be provided with means for draining the energy after the circuit has been opened. A discharge device should always be provided by the manufacturers as part of standard equipment.

A circuit-interrupting device of some form should in general, be used with capacitors to serve as a main switch as well as to provide overcurrent protection. As standard capacitors are designed for a permissible working voltage approximately 15 per cent in excess of rated voltage, and to provide for extra current due to possible harmonics, the main switch should have a capacity of at least 35 per cent over rated current of the capacitor.

In some cases, on 230-volt circuits, economies may be effected by using 460-volt capacitors and autotransformers, because of the lower cost per kilovolt-ampere of 460-volt capacitors. Since the capacitor is capable of handling a maximum of 135 per cent of normal kilovolt-amperes, the transformer output rating should be selected accordingly.

The possible short-circuit current at the installation should, of course, be considered when selecting the interrupting device. The circuit breaker selected must be able successfully to clear the maximum short circuit that may occur at that point.

Indoor installations of capacitors ordinarily do not require special consideration in regard to lightning protection. If the secondary circuit to the consumer presents any appreciable exposure the lightning arrester ordinarily installed to protect the consumer's apparatus will provide sufficient protection for the capacitors.

Outdoor capacitors should be protected by distribution-type lightning arresters, except where existing lightning arresters on the circuit are sufficiently close to the point of installation to provide protection.

Effects of Low Power Factor

The question of point of application of the capacitor is usually one of economics. The greatest benefit, from the electrical standpoint, can be derived from capacitors connected directly at the motor terminals, since they reduce power losses in all lines and transformers between the power source and the motor. However, such capacitors usually have a higher cost per kilovolt-ampere than equipment installed in larger blocks at the bus or on the primary feeder. The higher cost of low-voltage units must be weighed against the cost of a primary equipment plus additional copper for the low-voltage feeders, if some of these are overloaded or voltage drops are excessive. Also improvement in voltage obtained by capacitors on the low-voltage transformer secondaries, may warrant the higher first cost of a low-voltage installation.

Figure 5. Three hundred-kva 4,000-volt 3-phase 60-cycle outdoor large rack capacitor

It is often found that no more load can be added to a circuit because the wattless current has overloaded the system. By improving power factor, more load can be added at a lower over-all cost than would be incurred by installing more copper or additional circuits.

Low-power-factor conditions in a plant produce low voltage and excessive dips upon overloads and peaks. Starting and running torques of motors are reduced in proportion to the square of the voltage. Motors start slowly or not at all and may be stopped on voltage dips through action of the undervoltage device. The slip of induction motors is greater at reduced voltage, hence production suffers.

Of course, if the transformer bank is overloaded low-voltage capacitors will easily prove themselves out in comparison with additional transformer capacity.

A point which is sometimes overlooked or misunderstood when considering the effect of capacitors on an industrial load, is the fact that although the power factor of a motor is higher at full load than at part loads, the reactive kilovolt-amperes are also higher. Therefore to raise the power factor to unity requires slightly greater corrective kilovolt-amperes at full load than at part load. For example the full-load power-factor of a 10-horsepower 1,800-rpm squirrel-cage motor is 89 per cent and the lagging reactive kilovolt-amperes is 4.5 At half-load the power factor of this motor is 75 per cent and the lagging reactive kilovolt-amperes 3.9.

The thought is quite frequently expressed that, to meet certain conditions, capacitors should be installed on a motor to reduce starting current. When consideration is given to the fact that the full-voltage starting current of a normal-torque low-starting-current squirrel-cage motor is $4^1/_2$ or $5^1/_2$ times normal and its power factor at start may be 40 per cent or lower, it is readily seen that an unreasonable amount of capacity is required.

If starting current is important, the wound-rotor motor offers a better solution to the problem.

If power is generated instead of purchased, it may be necessary to improve power factor to relieve overloaded feeders or an overloaded generator. Most generators are rated on the basis of 80 per cent power factor. Therefore, unless the prime mover is oversize, there is little to be gained by raising the power factor above 80 per cent. For example, if a 500-kw 625-kva 80-per cent-power-factor generator is actually carrying 450 kw at 60 per cent power factor or 750 kva, and if the prime mover is capable of driving the generator with a 550-kw load a capacitor may at first be installed simply to bring the current within the rating of 625 kva. This would take 170 kva. Later, to provide for expansion extra units may be installed.

Assuming the additional load would also be at 60 per cent power factor, it would require 280 kva additional to reduce the total kilovolt-amperes to 625 with a 550-kw load. The corrected power factor would be 88 per cent. Whether the industrial company purchases or generates its power, a power-factor study is warranted because savings may be possible which may far exceed the cost of corrective capacity required.

Multiple Lightning Strokes—II

By K. B. McEACHRON
FELLOW AIEE

THE multiple stroke has been defined as a succession of discharges in substantially the same path, either between clouds or between cloud and ground. Multiple strokes are of considerable interest to the engineer, because of the possible effects of successive application of impulses to equipment with a very small cooling or resting period interposed. The author has undertaken studies of natural lightning in three different locations with three somewhat different methods, one of the objects being in each case the determination of characteristics of multiple strokes. One of these investigations is a detailed study of lightning strokes to the Empire State Building in New York, another in Pittsfield, Mass., employs photographic methods making use of an observatory erected for the especial purpose of studying lightning, and the third is an investigation of multiple strokes to transmission lines as measured by the use of the especially designed crater lamp oscillograph installed and operated in co-operation with the American Gas and Electric Company at Roanoke, Va.

These three investigations have all been in operation for three or more lightning seasons, but because of the large amount of data obtained from the other investigations, it will be necessary to confine the present paper to the results obtained in Roanoke, although naturally the results from the other investigations will influence the point of view.

Photographs showing the multiple character of some strokes of lightning have long been in existence, but it seemed to be important to find out how many of these effectively applied successive impulses to electrical apparatus connected to transmission lines. Fortunately, the application of the expulsion protector tubes supplied a means of determining, through the use of magnetic oscillograph elements arranged to record fault currents to ground, some of the successive discharges of a multiple stroke, since the protector tube allows but one-half cycle of power current to flow following each impulse. Of course such a method does not indicate the presence of more than one discharge in any one-half cycle, and from photographs of strokes it is known that successive discharges may be as close together as a few hundred microseconds. Recognizing this situation, during one lightning season a circuit was set up with a capacitance coupling to the transmission line, in such a manner that it was hoped to superimpose any during-half-cycle impulses, but none were found. This does not indicate that they were not present, rather that the system used was not able to record them, and if they are to be recorded other methods will have to be used. It will be readily understood that on a line not equipped with expulsion tubes the continuous flow of fault current obscures the effect of successive lightning discharges.

The crater lamp oscillograph[1] was installed in Roanoke early in 1934, and connected to read fault current to ground in each of the three phase conductors of the number 1 circuit of the double-circuit 138-kv Roanoke-Glenlyn line,[2] and the fault current in phases 1 and 2 of the Roanoke-Danville line. The sixth vibrator was used to record the potential to ground of phase 1 of the Danville line. The results obtained during the first year of operation of the oscillograph were reported to the Institute in December 1934.[3] The present paper will present the results of four lightning seasons beginning with 1934.

Paper number 38-40, recommended by the AIEE committee on power transmission and distribution, and presented at the AIEE North Eastern District meeting, Lenox, Mass., May 18-20, 1938. Manuscript submitted November 3, 1937; made available for preprinting March 26, 1938.

K. B. McEACHRON is research engineer with the General Electric Company, Pittsfield, Mass.

1. For all numbered references, see list at end of paper.

Analysis of Results

In analyzing the 295 records obtained in Roanoke, judgment must be exercised because a flow of current on either of the two lines being studied will draw current from the other, since they are bussed together at Roanoke. This is illustrated in the typical oscillogram of figure 1, where the stroke was to the Glenlyn line. It was assumed, however, that simultaneous strokes to the same phase conductors did not occur on the Glenlyn and the Danville lines. While such an occurrence is possible, it is too unlikely to be given weight.

Obviously, the operating data of the two lines were studied carefully, and circuit breaker operations correlated with the crater-lamp-oscillograph records. The *PM*-13 oscillograph at Glenlyn recorded the fault currents flowing in both of the Glenlyn circuits, and the records were studied with engineers of the American Gas and Electric Company. The *PM*-13 records were particularly helpful in studying the performance of the number 2 circuit of the Glenlyn line, which was on the same steel towers but which was not equipped with protector tubes. Oscillograph records which did not cause power follow current through protector tubes were neglected as being too uncertain. If included, these would add to the number of single-stroke records obtained.

Although some data from the Carolina Power and Light Company were included in the 1934 paper by the author, the data in the present paper are confined to the lines of the American Gas and Electric Company.

Table I. Occurrence of Strokes

Year	Total Strokes	Single Discharges	Multiple Strokes			Number of Storms Giving		
			Number	Per Cent	Discharges	Single Strokes Only	Multiple Strokes Only	Single and Multiple
1934	42	32	10	24	44	11	3	2
1935	21	19	2	9	4	9		2
1936	45	32	13	29	38	6	1	9
1937	76	49	27	35	90	13	2	11
Total	184	132	52	28	176	39	6	24

Frequency of Occurrence

A total of 184 strokes was recorded by the crater lamp oscillograph, of which 52 are known to be multiple. Out of 69 storm days, 39 yielded 73 single strokes; 24 days gave 59 single and 42 multiple

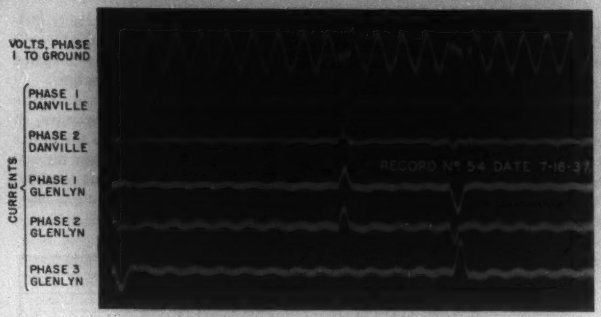


Figure 1. Crater lamp oscillogram showing operations of expulsion protective gaps on successive lightning discharges to the Roanoke-Glenlyn line

strokes; and on 6 days only, 10 multiple strokes were recorded with no single strokes. These data seem to indicate that certain storms produce few if any multiple strokes, and other storms seem to have on the average about an equal number of single and multiple strokes.

In view of the New York investigation, it does not appear strange to find some degree of similarity between strokes in the same storm as to general characteristics. Cloud formation is probably responsible for the different characteristics of lightning when one stroke is compared to another, and it is probable that the controlling conditions lie in the cloud itself. There is evidence to indicate that the same cloud center will tend to continue to produce the same type of discharge, at least while discharging to objects within a limited area.

When considering the data presented in this paper, it is recognized that great accuracy is not possible, since a certain number of single strokes are not recorded which did not cause tube follow current and multiple strokes with time intervals less than one-half cycle are not identified. In table I the data obtained are given by years.

The importance of the multiple stroke is realized when it is considered that of the discharges recorded, 176 or 57 per cent of the total discharges were multiple, or putting it another way, 28 per cent of all the strokes produced 57 per cent of the discharges.

A brief comparison with the results from Pittsfield, using a multi-lens moving-film camera will be of interest. During the years 1935, 1936, and 1937 a total of 73 storm days were recorded. Two hundred thirty-two strokes were photographed, of which 55, or 23.7 per cent, were multiple. This percentage is lower than the true number, since the photography becomes poor at distances of several miles under weather conditions often existing. The check, however, with the Roanoke data is quite good, indicating that roughly one-fourth of the strokes over a period of years consist of more than one discharge.

Multiple Stroke Data

A summary of the data obtained is given in figure 2, where each multiple stroke is plotted against its time duration in cycles (60 cycles). The maximum time duration is still as it was reported in 1934, namely, 40 cycles. Although, if enough data were available, a somewhat longer time might be found, yet other work not yet published indicated that the probable maximum time will not much exceed one second. When examining these data, it should be realized that there are many multiple discharges which will not have sufficient magnitude to cause a second tube operation, and thus would not get in the record. Thus data, on multiple strokes close by, obtained by photographic means, may differ somewhat from that obtained from an investigation of this sort even of the same strokes. There is also another point of departure, in that another stroke could occur to the ground wire within a second of time at other points and the oscillograph could not identify them as being of the same multiple discharge. This possibility, based on other observations, can be dismissed as being highly improbable in any appreciable number of cases.

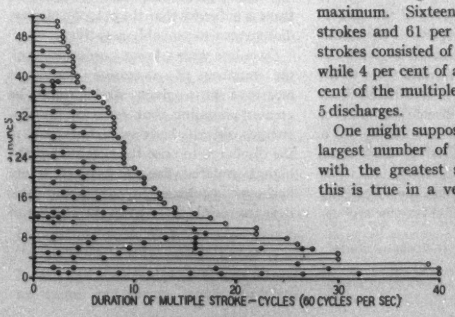


Figure 2. Distribution of multiple strokes and discharges

Time Interval and Number of Successive Discharges

The time interval between successive discharges is important, since it has to do with the rest period afforded insulation, whether air or solid before being restressed. In figure 3 the data of figure 2 have been replotted to show the time intervals and the frequency of their occurrence per 100 discharges. The longest time was 26 cycles between discharges, while the shortest time will of course be zero cycles when current flows in two succeeding half cycles. The maximum time recorded is of considerable interest from the point of view of deionizing time of the air under lightning conditions.

In Pittsfield, the longest time between successive strokes was 0.44 second, which is slightly over 26 cycles. It might be argued that in the case of the crater-lamp-oscillograph data, a second stroke caused the record at the 26 cycle point, but the Pittsfield photographs show discharges in substantially the same path 0.44 second later, so it appears that a time as long as 26 cycles is possible.

Concerning the minimum time, nine per cent of the discharges occurred with a time interval of one cycle. Lacking means for determining shorter times, in this particular investigation no conclusion can be drawn. However, in the Pittsfield investigation, times shorter than 0.0005 second were measured between discharges.

The number of successive discharges as shown in figure 4 vary up to 12 as a maximum. Sixteen per cent of all the strokes and 61 per cent of the multiple strokes consisted of at least 3 discharges, while 4 per cent of all strokes and 15 per cent of the multiple strokes had at least 5 discharges.

One might suppose that in general the largest number of discharges would go with the greatest stroke duration, and this is true in a very general way, but

the data show serious exceptions since one 40-cycle stroke had 12 discharges and a 39-cycle stroke had 3, while a 6-cycle stroke had 4 discharges.

Discussion and Conclusions

This investigation indicates clearly that multiple strokes do take place to transmission line conductors and must be considered in any protection setup. Protective devices designed to protect apparatus from the effects of lightning should not include mechanical motions which take time for restoring to normal condition if proper protection is to be maintained.

In the four-year investigation, 308 discharges were recorded from 184 strokes. Fifty-two multiple strokes yielded 176 discharges. Approximately 25 per cent of all strokes were multiple. The largest number of successive discharges was 12. The longest time between the first and last discharge was 0.66 second or 40 cycles, while the shortest time is not indicated from this investigation. Other

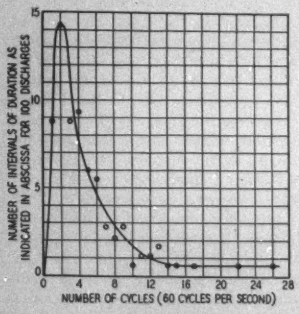


Figure 3. Time intervals between discharges in multiple lightning strokes

work shows a time as short as 0.0005 second.

As to the characteristics of the successive discharges with regard to the initial discharge, little information is given, except that a study of the data seem to indicate more current is associated with the multiple stroke discharges than in general occurs with strokes having but a single discharge. There is also some tendency for the first discharge of a series to pass more current than the succeeding discharges. These observations are deduced from a study of the number of phases involved with the different discharges.

There appears to be a definite tendency for some storms to produce more multiple strokes than others. In fact as far as the records of strokes to the transmission line are concerned, more than half of the storms did not produce multiple strokes. This is probably related to the cloud

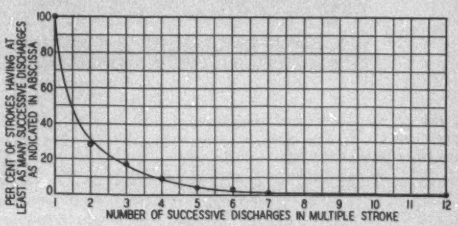


Figure 4. Number of successive discharges in multiple lightning strokes

structure and the disposition of charges within it.

In general, the multiple strokes which occupy the greatest time between the first and last discharges will have the greatest number of discharges, although this is not always true. The methods used could not distinguish between discharges occurring during a half cycle of protector tube follow current.

The great majority of the follow currents measured were positive in polarity indicating a negative direct stroke. This is in agreement with the work of Lewis and Foust,[4] who found that of 358 strokes recorded during the years 1934, 1935, and 1936 through tower legs of transmission lines, approximately 95 per cent were negative. Since the succeeding strokes did not show a polarity of follow current particularly different from the first discharge of the series, there seems to be no evidence which indicates a reversal of polarity as between the first and succeeding discharges, rather such evidence as there is indicates that the polarity of most discharges was probably negative.

On a line with a lower insulation level, the number of successive discharges measured in a given stroke would be greater assuming that some of the discharges did not have enough current in the discharge to raise the potential of the higher-insulated line to a point where flashover would occur. This indicates that the results given as to the number of successive discharges is probably pessimistic for low-voltage circuits where the apparatus strength may be low compared to the insulation strength of the line.

In thinking about the effects of multiple strokes upon connected apparatus, it should be remembered when the stroke takes place some distance from the station, assuming a line without overhead ground wire protection, and a line flashover occurs, only the first impulse of the series will be transmitted along the line unaffected by the tower footing resistance of the flashed structure. Succeeding discharges in the stroke will develop potentials on the line dependent upon the *IR* drop through the tower footing resistance.

Where overhead ground wires are used, and strokes do not contact the line conductors, the potential of the traveling wave, both for the first discharge and succeeding ones will be dependent upon both the footing resistance and the current in the various discharges. Under these conditions, many low-current discharges which are observed upon moving-film photographs of direct strokes would not be of serious consequence with reference to connected apparatus. It is at this point that the investigation is probably of greatest value, in that it indicates the number of successive discharges which had sufficient magnitude to cause operation of the protector tube.

References

1. Crater Lamp Oscillograph, W. A. McMorris, M. A. Rusher, and J. H. Hagenguth. *G. E. Review*, November 1934, page 514.

2. Expulsion Protective Gaps on 132-Kv Lines, Philip Sporn and I. W. Gross. AIEE Transactions, 1935, page 66.

3. Multiple Lightning Strokes, K. B. McEachron. AIEE Transactions, 1934, page 1633.

4. Lightning Investigations on Transmission Lines—VI, W. W. Lewis and C. M. Foust. Electrical Engineering, January 1937, page 101.

Photoelectric Weft-Straightener Control

By C. W. LaPIERRE
ASSOCIATE AIEE

A. P. MANSFIELD
NONMEMBER AIEE

THE PROCESS of weaving consists of interlacing spun threads at right angles on a loom, figure 1. In the woven material thus formed, of which cotton cloth is a very common example, the lengthwise threads are designated as the "warp" and the crosswise or filling threads are designated as the "weft," figure 2.

As woven, the weft threads of fabrics are substantially at right angles to the warp threads. Numerous subsequent finishing processes involve rehandling the wet material in rope form. When finally stretched and dried, much of the cloth will not have weft and warp threads at right angles in spite of inspection and manual means for mitigating this defect. This skewed goods tends to change shape with use so that fit or hang or design does not hold up to the purchaser's expectations.

This paper describes a successful automatic means, for squaring up the goods in the final drying and stretching process, thus making it possible to raise materially the textile finishing standards in this respect.

The size of the threads and the number used per unit area varies widely. Likewise grouping, and arrangement of threads to form patterns are subject to wide variations. In general, however, it may be said thread diameters range from 0.005 inch in fine shirting to 0.050 inch in heavy duck. Also, thread counts as low as 20 per inch are used in open-weave marquisettes while in fine shirting as high as 100 per inch are frequently found. Still others use as high as 136 warp threads with 60 weft threads. Cloth is produced in a great variety of widths, ranging from 30 to 108 inches and many hundreds of feet in length.

Cloth as it comes from the loom is strong and serviceable and a limited amount of it is used as "gray goods"; another name for "unbleached cotton cloth," but most of it, some 90-odd per cent of it, is "bleached" to give it that fine white well-known appearance. The bleaching operation involves much rough handling; treatment with chemicals, subsequent washing, and in most cases starch is added to improve its appearance. Cheaper grades are also filled with talc or white clay.

In the process of finishing, the cloth must be transported from one vat to another which may be a thousand feet or more away. Transportation is usually effected by pulling the cloth in rope form from one vat to another, often over a circuitous route guided through large porcelain rings or "pot eyes," figure 3. This is harsh treatment as far as the structure of the cloth is concerned and it results in considerable distortion of the weave from the right angular relationship of the warp and weft threads so accurately woven by the loom.

Following the washing operation, the cloth is "beaten out" in a scutcher, to its original flat form, after which it passes through a starch mangle, figure 4, where the filling starch or clay is added and subsequently through drying apparatus to remove the wash water. The drying operation is accomplished with a combination of dry cans and tenter.

Dry cans consist of a series of steam heated cylinders arranged so that the cloth will pass from one to another, in contact with about three quarters of the circumference of each, figure 4. The temperature of the cans and speed of the cloth is controlled so that when leaving it contains a definite prescribed amount of moisture.

A tenter is a machine designed primarily to restore the cloth to its original width making due allowance for shrinkage, by exerting a suitable pull on the selvage edges at opposite ends of the weft threads, figure 5. Frequently tenters are enclosed in ovens and the sizing and drying operation combined either wholly or in part.

In practice, depending on the type of cloth and the finish required, the cloth may be completely dried on a tenter, or stretched to the required size on a tenter and dried on cans or partly dried on a tenter and finished on cans; but regardless of the system used, the weave distortion or skew introduced in the previous processes must be removed; e. g., the cloth must be "straightened" to make it salable.

Cloth straightness may be defined as the perpendicular relationship between weft and warp threads, also deviations from straightness may be expressed as "skew." It is very essential that cloth be straight, both in plain fabrics as well as those embodying woven patterns. Similarly cloth should be straight before being printed, otherwise, the pattern will be distorted after the cloth is cut into small pieces, such as required for curtains or wearing apparel.

The straightening operation should be performed on the cloth while it is moist as the fibers are then pliable and susceptible of proper positioning. Straightening is accomplished by moving the selvage on one side with respect to the other, an amount necessary to correct the distortion.

Several machines are now on the market for straightening cloth which perform with a fair degree of success. One of the more common is the "swing tenter" in which an oscillating movement of one chain with respect to the other is introduced which tends to "spread" the skew over the entire area, thereby reducing the magnitude of the distortion in any particular area. Strictly speaking, this device could not be classified as a "straightener," but rather one to even out the peak skews to passable limits in cloth where true straightness is not required.

In the "canting roll" type shown in figure 6, the cloth which has been previously spread to its full width is passed over two or more rolls, the ends of the axes of which are made to approach or recede from each other, thereby slackening or stretching the selvage as may be necessary to introduce the required correction.

Still another type of straightener performs the straightening operation in the tenter by advancing or retarding one chain with respect to the other so that the perpendicular relationship is secured in the cloth as it leaves the tenter. Figure 7 shows one way of accomplishing this. A differential gear is introduced in the main drive shaft by means of which the position of the left-hand chain may be advanced or retarded with respect to the right-hand chain by adding or subtracting revolutions to the main drive shaft. The differential is operated by a small motor, which is controlled in terms of cloth skew as observed at the leaving end of the tenter.

With manual control of the motor, the operator must visualize the skew and manipulate the motor switch accordingly. Obviously, this procedure is subject to

Paper number 38-42, recommended by the AIEE committee on general power applications and presented at the AIEE North Eastern District meeting, Lenox, Mass., May 18–20, 1938. Manuscript submitted February 25, 1938; made available for preprinting March 31, 1938.

C. W. LaPIERRE and A. P. MANSFIELD are employed by the General Electric Company, Schenectady, N. Y.

Figure 1. Loom showing cloth in process of being woven

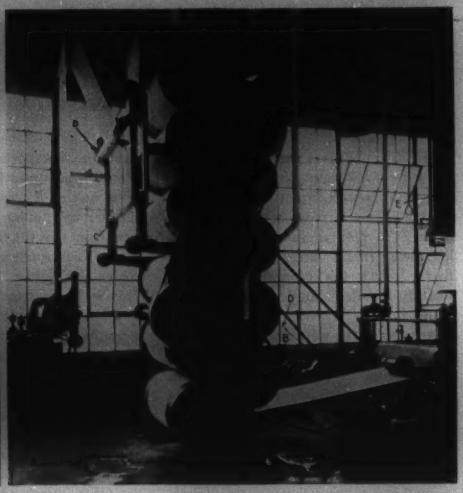


Figure 4. "Dry cans" for drying cloth, with starch mangle at right

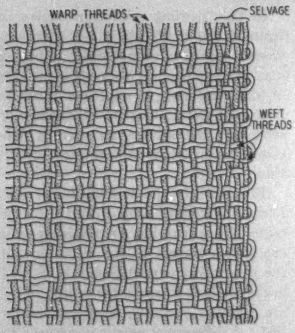


Figure 2. Typical woven material

human limitations and restricted to relatively coarse weaves and low cloth speeds, hence the development of an automatic control became necessary to meet present day standards of finishing with high cloth speeds now employed.

Automatic Control

Principles

To automatically control the weft straighteners just described, a method of detecting skew is necessary. Figure 8 illustrates the method of this paper; (*a*) represents weft threads of cloth of one direction of skew; (*b*) cloth having no skew; and (*c*) cloth having the other direction of skew. Outlined on these weft threads are two convergent paths, *A* and *B*, each traversed in the direction indicated by spots of light. In figure 8(*a*), light spot *A* crosses 15 weft threads and spot *B* nine weft threads; in figure 8(*b*) each spot crosses 12 weft threads; and in figure 8(*c*) *A* crosses nine threads and *B* 15 threads. Thus, if weft threads can be made to intercept two spots of light in this manner, a comparison of the rates at which the two spots are intercepted will indicate the direction and magnitude of the angle of skew.

In a practical case, convergent light spot paths can be obtained by moving the two light spots laterally as in figure 8(*d*).

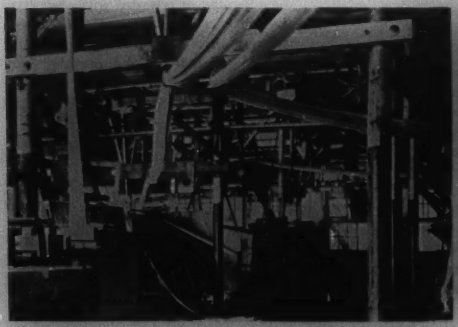


Figure 3. Transportation in rope form through "pot eye" guide

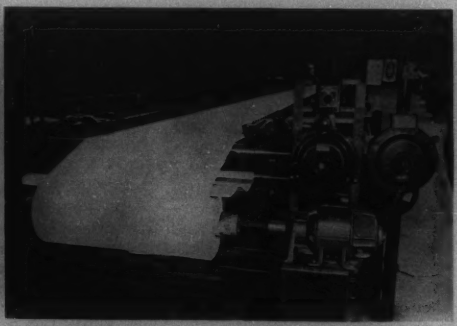


Figure 5. Tenter for restoring cloth to proper width

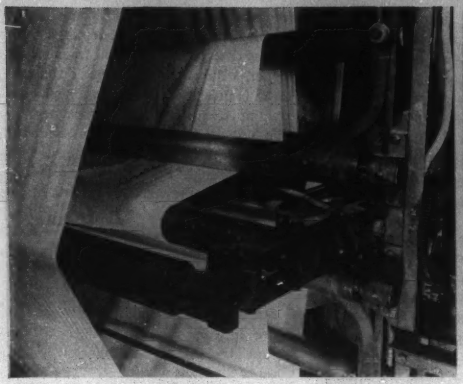


Figure 6A. Canting-roll type of straightener

Figure 6B. Canting-roll type of straightener

The cloth moving forward as the spots move inward will produce the required diagonal paths.

To carry out such a principle two things are necessary; first, suitable scanning detectors which will give an impulse for each weft thread interception in the manner just described; and second, a control circuit which will compare the impulse rates from the two scanning detectors and operate the straightener motor when necessary to make the two detectors generate impulses at the same rate.

Scanning Detector Unit

A device for accomplishing the first of these requirements is illustrated in figure 9. A pair of these, one near each edge of the cloth, comprise the complete scanning system of the weft-straightening control.

Each of these scanning units comprises six parts, namely: (1) a scanning optical system; (2) scanning disk; (3) scanning table; (4) detector optical system; (5) amplifier; and (6) a good rigid framework to hold these parts together.

Scanning Optical System

The scanning-unit optical system is shown in figure 10*A* and *B*. The straight filament of the lamp is focused on a slit which in turn is focused on the cloth be means of cylindrical lenses at the end of the optical system housing. The line of light so formed by these lenses is approximately 0.0035 inch by two inches.

The final spot after passing through the scanning disk is 0.0035 inch by 0.063 inch. Its dimensions are determined by the maximum number of threads per inch and their size. Thus it must be thin enough to be completely intercepted by one weft thread. It must be wide enough to span a number of warp threads; otherwise, the warp threads will generate a frequency too. On the other hand, the spot cannot be too wide or at large angles of skew, the weft threads will cross the spot diagonally and not intercept it.

These dimensions are important and are subject to precise calculation for any given set of conditions.

Scanning Disk

The scanning disk is illustrated in figure 11. It is a simple circular duraluminum disk with 16 radial slots $^1/_{16}$ inch wide. The disk is driven at a speed proportional to the cloth speed by means of "Selsyns," the transmitter of which is coupled to the main tenter drive. Thus, the lateral motion of the spot bears a constant relation to the forward motion of the cloth, or in other words, the angle of the path of the light spot is constant.

Scanning Table

Due to the short focal length of the cylindrical lenses, it is necessary that the cloth be held flat at the focus of the light

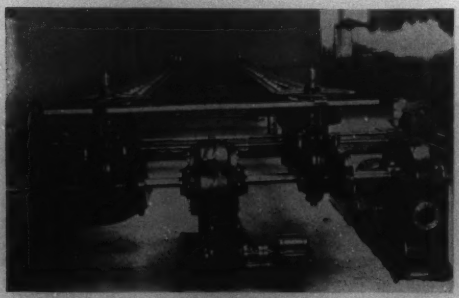


Figure 7. Tenter differential straightener

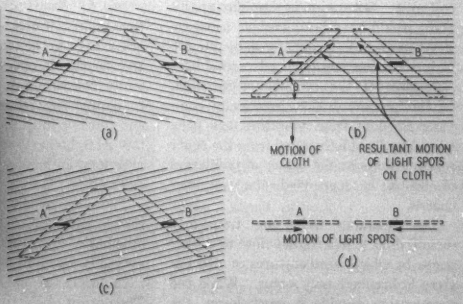


Figure 8. Principles of skew detector

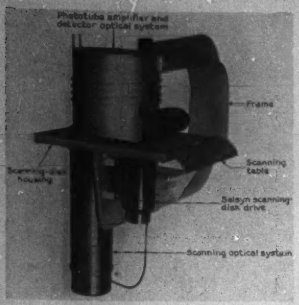


Figure 9. Scanning unit

spot. This is accomplished by passing the cloth over a smooth flat table having a window over the light spot, figure 12. This table is mounted about $^1/_4$ inch above the normal cloth level so the cloth is drawn smoothly taut across it.

Detector Optical System

After passing through the cloth, the spot of light strikes a large spherical lens in the phototube amplifier housing where it is focused on a phototube, figure 13.

Phototube Amplifier

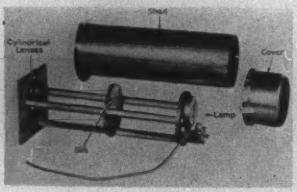
The interruption of the light by the weft threads causes impulses in the output of the phototube. These impulses are amplified by the phototube amplifier before the control transmission unit, figure 14.

The frequency range of the amplifier is from approximately 200 to 12,000 cycles. The gain increases somewhat with frequency to compensate for circuit losses. The primary reason for locating an amplifier in the phototube housing is to change the high-impedance phototube circuit into a low impedance output circuit suitable for transmission to the control unit. Otherwise, an amplifier at this point would have been avoided as excessive vibration is frequently encountered. This vibration has required careful consideration of the amplifier suspension. In the present device, practically complete freedom from vibration has been gained by flexibly hanging from the cover a heavy mass at the center of oscillation of which is suspended the amplifier chassis.

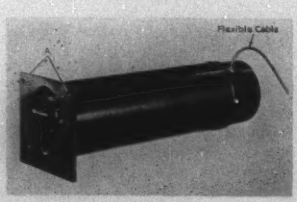
The scanning units are frequently mounted on tenter frames close to drying ovens in which temperatures of 250 degrees Fahrenheit may occur. While the temperature outside is much lower, the phototubes have a maximum allowable temperature of 150 degrees Fahrenheit so in some cases it is necessary to cool the phototube-amplifier housing. This is accomplished by passing cooling water through a few turns of copper tubing soldered to the housing. Very little water is required as the housing should not be cool enough to condense moisture and drip it on the cloth.

Control Unit

The design of the phototube detector and amplifier as described has proved to be subject to engineering calculation. The design of the control unit, on the other hand, has required a considerable amount of experience to insure proper functioning of the equipment. The control unit performs three major functions: first, it compares the impulse frequencies from the two scanning detectors; and second, it operates the straightener motor contactors in the proper direction to correct any skew which may exist; and third, it must so adjust its control of the straightener motor that it will not overshoot in making the necessary correction.



A—Covers removed



B—Assembled

Figure 10. Scanning-unit optical system

The unit which accomplishes this is shown in figure 15*A*, *B*, *C*, and the schematic diagram of the circuits involved is shown in figure 16.

In brief, the operation is as follows: The output of the two scanning detectors is amplified further and passed to the frequency comparator which compares the impulse frequency from detector A with that of detector B. If either frequency is higher, a d-c potential appears on capacitor C_1 of polarity dependent upon which is greater, frequency A or frequency B. The potential, which is a measure of magnitude and direction of skew, then passes through the antiovershoot network and is impressed upon the relay tube which in turn operates relays and they in turn operate small contactors and finally the straightening motor contactor.

Frequency Comparator

Starting with the input amplifier A of figure 16, each impulse produces at the output transformer secondaries a full cycle of alternating current. The initial half cycle of this impulse makes tube A_1 conducting and thereby charges capacitor C_{1A} positive. The second half cycle of the impulse shuts off tube A_1 and makes tube A_2 conducting so that the charge accumulated by C_{1A} is passed to C_1. Thus, each impulse from A first charges C_{1A} positively to approximately one-half the supply voltage and then dumps this charge into C_1 on the next half cycle.

Similarly, the first half cycle of impulse from B charges C_{1B} negatively to approximately one-half the supply voltage and then dumps this charge into C_1 on the next half cycle.

Thus, if impulses arrive from A faster than from B, C_1 will accumulate a positive charge, and if they arrive faster from B than from A, C_1 will accumulate a negative charge. The charge across C_1 is filtered by resistors R_3 and appears across C_3 as the potential E which is a measure of the magnitude and direction of the skew.

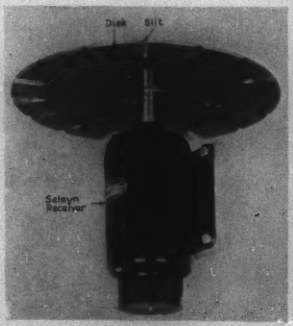


Figure 11. Scanning disk

Overshoot Prevention

Actual experience in operating automatic weft-straightening controls has shown that care has to be exercised to prevent the correction from overshooting. Consequently, the potential E cannot be used directly on a polarized relay to operate the straightening motor.

The network preceding the relay tube prevents overshoot by doing two things: first, it throws the straightener motor on and off in such a manner as to cause the correcting rate to be somewhat proportional to the amount of skew; second, if there is a considerable skew which decreases suddenly due to the cloth coming through more nearly straight, the network will shut off the straightening motor and hold it off until the skew stops decreasing.

The network is composed of simple resistors and capacitors coupled to contacts on the motor relay contactors.

This action may be explained by the circuit diagram. Under the conditions of figure 16, the straightener motor is not operated. If a skew comes along, C_3 takes on a charge E, which throws one of the grids of the relay tube negative so that its relay drops out and closes the motor contactor. When this happens, the corresponding contact in the anti-overshoot circuit shifts to "in" placing the capacitor C_4 in series with the corresponding grid. This produces no immediate change because the capacitor C_4 has zero voltage. However, as C_4 becomes charged, the negative voltage on the grid decreases until the relay drops out, the straightener motor stops and the contact returns to "out." Capacitor C_4 is now charged and will discharge through R_3 tending to hold the relay-tube grid positive and keep the motor stopped until C_4 is discharged. If there is still a considerable skew, however, the skew control potential E will exceed the effect of the discharging C_4 and the relay will drop out right away and start the motor again. If E is small, a considerable time will elapse before the grid goes negative enough to start the motor. Thus, the circuit starts and stops the straightening motor frequently and the amount of time the motor runs as compared with the amount of off time is a function of the magnitude of the skew. For large angles of skew, the straightening motor will run most of the time and be off but a small part of the time. On the other hand, for small angles of skew, the motor will be off most of the time and will run only a small part of the time.

This explanation covers more or less the static operation of the circuit. In any particular case, the skew-control potential E is likely to be changing continuously. These changes are transmitted through the capacitor C_4 and if sufficiently large will cause the relay circuit to operate on the direction of the change rather than upon the magnitude of the skew. Thus, if E is increasing, the capacitor C_4 will start the motor running more quickly than would have been the case if E had not changed during the sequence of events. Thus, the circuit anticipates to a considerable extent the coming skew condition of the cloth and controls the straightening motor accordingly.

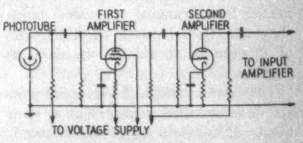


Figure 14. Schematic diagram of phototube amplifier

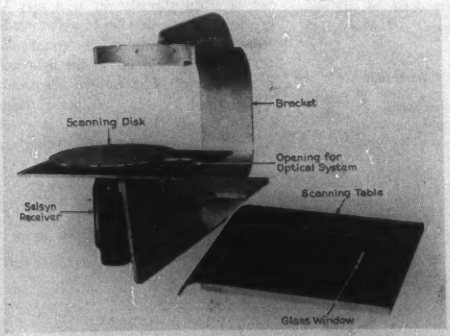


Figure 12. Scanning table with window and main bracket

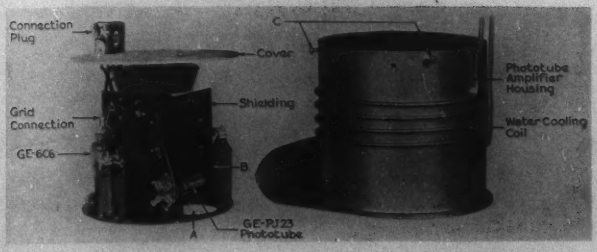


Figure 13 (below). Scanning-unit detector

Relay Circuit

The relay circuit comprises a twin triode with a relay in each plate circuit. The relays are normally closed and are interlocked so that the motor contactors will be closed only if one of the relays opens and the other remains closed.

Control Contactor Circuit

The relays cannot handle the motor contactors directly so some control contactors are also necessary. These control contactors carry the antiovershoot contacts described above.

Safety Circuit

The circuit of figure 16 performs one additional function. In case a large skew-control potential appears, it is probably due to a fault. The cloth may have torn or pulled out of the tenter on one side so that only one detector is functioning or a tube may have failed, the angle of skew may be too great for the detectors to handle, etc. Under these conditions, the safety circuit relay will drop out, opening the motor circuit, light a red lamp or ring a signal, or both.

Associated Equipment

In addition to the scanning and control unit, the other electrical equipment required for automatic weft straightening includes the straightener motor with

brake and contactors. These devices must withstand frequent operation and reversals.

Installation

The installation of the equipment is simple, as the complete scanning unit is mounted on one bracket which bolts to the tenter rail, figure 9. The control unit is bolted to a wall or panel by four bolts, figure 15*C*.

Because of the high frequencies transmitted from scanning to control units, the connections between the two pieces of equipment should be as short as possible.

The point at which the scanning units are to be installed is important in some cases. If the cloth under the scanner is completely dry and not pliable, the fact that it is straightened at that point does not mean it will remain straight after it leaves the tenter, because it will tend to return to the condition under which it was dried.

Cloth speed is important because it determines, together with thread count, the maximum frequency of the impulses to be handled. The equipment is now rated at a maximum of 140 yards per minute. At this speed with 80 threads per inch, the thread frequency is 6,720 per second. With a skew of approximately four inches in 40-inch-wide cloth, the frequency one scanner must handle is approximately 12,000 per second.

The maximum frequency to be handled may be further raised by the presence of "bow" in the cloth. Although symmetrical bow affects both scanners similarly and consequently does not cause operation of the straightener, bow may, in special cases push the frequency beyond the range of the amplifier, or it may be of such a sharp angle that the weft threads pass the light spot at such an angle that they do not intercept it. Figure 17 illustrates typical forms of skew and bow.

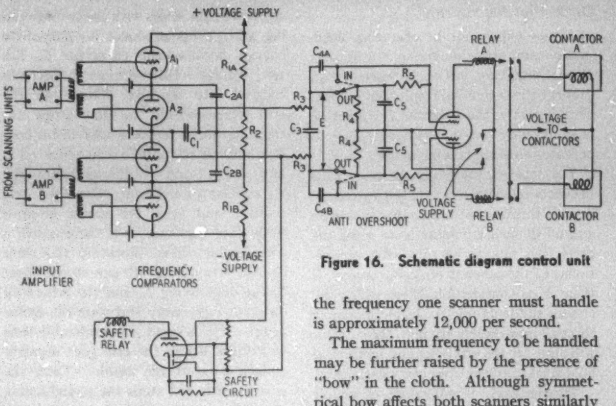


Figure 16. Schematic diagram control unit

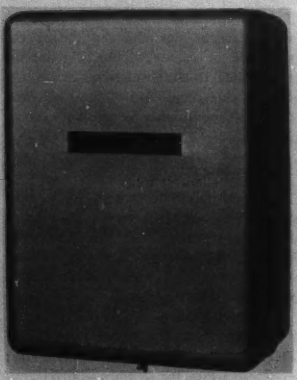
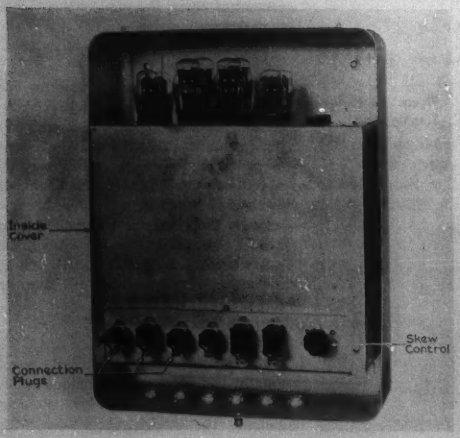


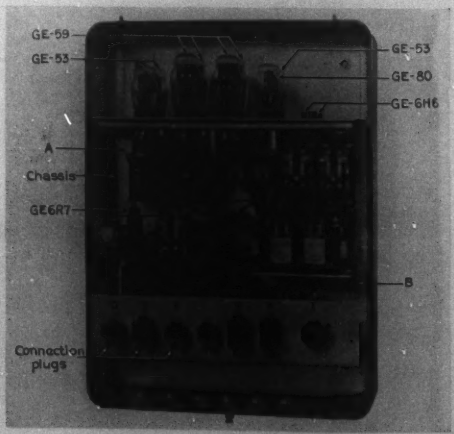
Figure 15. Control unit

A (left)—Completely assembled
B (lower left)—Main cover removed
C (lower right)—Chassis cover removed

Cloth Limitations

Most cloth is of the type illustrated in figure 2, although in much of it the number of warp threads per inch may be greater than the number of weft threads. All such cloth, however, has a rectangular texture when held up to the light and practically all of it can be adequately straightened by the weft straightening control. Some cloth, however, is woven to form patterns or the threads may not





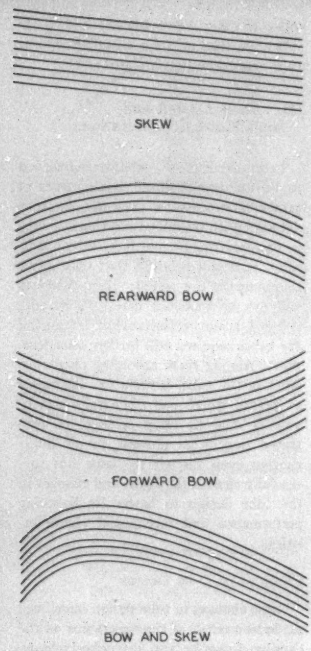


Figure 17. Typical forms of skew and bow

interlace adjacent threads. In such cases, each kind of cloth must be inspected closely to determine whether it can be handled by the automatic scanning unit. In many cases, cloth has actually been straightened which appeared hopeless at first inspection. Loosely woven marquisettes with large tufts have worked very well, even though each tuft blocks off a large part of the optical system.

The optical system was originally designed to handle 100 by 100 thread count which was thought to be about as fine as would be found. Experience now shows, however, that cloth with many more warp threads than weft threads is more difficult to handle than the finest square weaves. For instance, in some types of broadcloth with a weave of 60 by 136, the large number of small warp threads has little or no bending effect upon the relatively large weft threads and consequently the warp threads mat together and in some cases leave practically no interstices.

Another factor decreasing the amount of light is the amount of sizing applied to the cloth. In the cheaper grades of cloth, the interstices appear completely filled. However, the sizing must be at least slightly transparent, because in all cases so far encountered, successful straightening has been accomplished after some experimenting with proper location of the scanning unit.

As might be inferred, a color has no effect upon the operation of the control. The dye is a part of the thread fiber and does not fill the interstices.

Maintenance

In any equipment such as this, the question of maintenance is important. Controls have been in operation over a period of several months without attention and this is to be expected. The equipment contains, however, a number of electronic tubes having a life rating of 1,000 hours although experience has shown this rating to be conservative. The two lamps will ordinarily last several hundred hours, but this will depend to some extent upon the amount of vibration of the particular machine to which they are connected.

The electrical circuit in these controls is necessarily somewhat complicated for ordinary servicing. To facilitate such servicing, the phototube amplifier units and the control units are interchangeable, and in case of failure, a new unit can be substituted in a very few minutes. All connections are made by plugs so changes of units require no wiring.

Application

Several commercial installations of the automatic weft-straightening control have been made in conjunction with the differential-gear-type straightener, typical of which, is that at the Danvers Bleachery, Peabody, Mass. Cotton sheeting after being bleached and washed is finally sized in a twenty-foot tenter where it is automatically straightened, just prior to entering the dry cans. Figure 18 shows the arrangement of the scanning and control units, and figure 19 the complete tenter with dry cans in the background.

Acknowledgments

Any development of this nature is of necessity the result of co-operation of many individuals. The authors wish to acknowledge particularly the contributions of H. A. MacKnight of the Winsor and Jerauld Manufacturing Company who saw the need and participated in the application of the device; also the contributions of T. M. Berry and E. F. Travis of the General Electric Company for many of the essentials that have made the equipment so successful in the field.

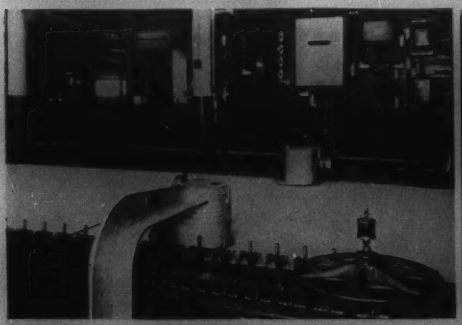


Figure 18. Close-up of Danvers Bleachery Installation

Figure 19. Installation at Danvers Bleachery

Protector-Tube Application and Performance on 132-Kv Transmission Lines—II

By PHILIP SPORN
FELLOW AIEE

I. W. GROSS
ASSOCIATE AIEE

I. Introduction

THE USE of protector tubes (previously referred to as expulsion protective tubes or "deion" gaps) during the past five years or so as devices for protecting transmission lines and equipment against lightning has gained considerable headway, particularly in the protection of high-voltage transmission lines. A number of applications have been made in the medium voltage transmission field, a few in the low-voltage field, and a number of scattered installations for protection of equipment and cables.

Since the protector tube was first proposed[1] as a protective device, considerable experience has been gained in making practical use of this device in the field. The development of any new type of equipment usually consists of a period of experimental work in the laboratory followed by field tests and then more or less limited operating experience before the merits of the device are fully proved. This situation has been true of the protector tube, which is now well past the first two stages of its development. As a matter of fact, the application and operating performance of the protector tube have found quite frequent space in the technical literature during the past few years.[2,3,7,9–19]

The performance of protector tubes on two 132-kv lines was described by the authors in a paper[3] presented two years ago. Since that time three additional 132-kv lines of the interconnected transmission system have been equipped with protector tubes. It is the purpose of this paper to now discuss the tube application to these lines, to give their operating performance, and to summarize the experience which has been obtained on the application and performance of protector tubes on some 250 miles of 132-kv lines equipped with these devices.

II. System Analyzed

The lines on which protector tubes were installed are 132-kv steel-tower lines of the operating companies of the American Gas and Electric Company. These lines are constructed with one ground wire and use standard suspension insulators. The circuits are in vertical configuration. All tower structures are of the double-circuit type. The Roanoke-Fieldale, Fieldale-Danville, and Turner South Point lines are single-circuit. The Glenlyn-Roanoke line is double-circuit, one circuit only being equipped with protector tubes. The Philo-Newcomerstown and Newcomerstown-Canton lines were formerly a continuous line from Philo to Canton, but during the period when equipped with tubes, they have operated as separate line sections, although still located on the same double-circuit tower structures which carry the still-existing Philo-Canton number 1 line. More complete information on the characteristics of the above lines has been presented previously.[4]

In table I is given pertinent information on these lines as regards protector-tube application. It will be noted that the tube-equipped lines comprise 255 miles of line, 1,080 towers, and 3,240 tubes. Dates of tube installation and tube current ratings are also given.

III. Tube Design and Installation Considerations

In an earlier paper,[3] what were believed to be the fundamental requirements of protector tubes were presented in some detail. With the added experience gained in the past three years from tube operations, it is still believed that these same requirements are sound; they therefore will not be repeated here. It has developed, however, that certain features of the tubes required still further consideration. Among these are aging characteristics of the tube, installation clearances at points where gas discharges are involved, delayed relay settings of protected circuits to prevent circuit interruption even though the tube has successfully cleared the fault, and changes in the tube design to better its lightning performance and mechanical characteristics.

Changes in Tube Design

Some changes in tube design have been made as a result of the experience on the Glenlyn-Roanoke and Roanoke-Fieldale-Danville lines previously reported.[3] Such a change was the result of an attempt to provide a better voltage grading along the surface of the tube. One method of accomplishing this is shown in figure 1 where grading shields have been applied to the tubes. This additional grading was provided on the Roanoke-Fieldale and Fieldale-Danville lines prior to the 1937 lightning season.

Another method used to improve grading along the tube was the use of a resistance material built into the tube itself. This type of construction was used on the more recent tubes installed on the

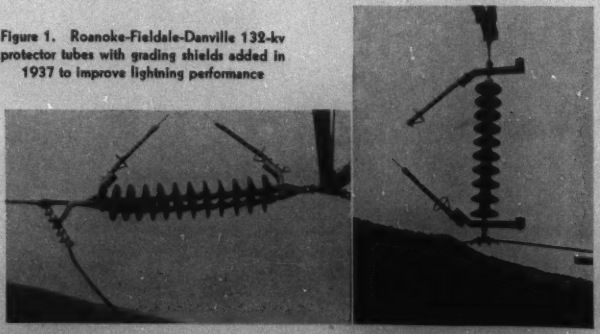


Figure 1. Roanoke-Fieldale-Danville 132-kv protector tubes with grading shields added in 1937 to improve lightning performance

Paper number 38-44, recommended by the AIEE committee on power transmission and distribution and presented at the AIEE North Eastern District meeting, Lenox, Mass., May 18–20. Manuscript submitted February 18, 1938; made available for preprinting April 12, 1938.

Philip Sporn is vice-president in charge of engineering of the American Gas and Electric Service Corporation, New York, N. Y., and I. W. Gross is electrical research engineer for the same organization.

1. For all numbered references, see list at end of paper.

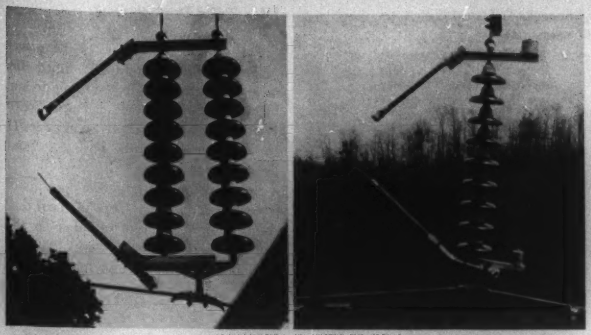


Figure 2. Protector tubes—V type—on Turner-South Point 132-kv line. Note double angle vent at air-gap end of ground tubes, and at bottom end of line tube on single-suspension assembly. Double-suspension assembly has L vent at bottom end of line tube. These types used on Philo-Canton and Turner-South Point lines

Philo-Newcomerstown, Newcomerstown-Canton, Turner-South Point, and most of the new tubes installed on the Glenlyn-Roanoke.

A second change made in the new tubes installed on the Philo-Canton, Newcomerstown-Canton, and Turner-South Point lines is shown in figure 2. This change deals largely with the venting of the gases. It will be noted that gases which formerly vented along the axis of the tube straight into the external gap have now been diverted with a Y fitting at the free end of the tube and so designed as to throw the gases clear of any conductor or grounded structure in the direct path of the discharge. Similarly, venting at the rigid end of the tube has been changed to divert the gases by an L fitting to throw them away from the conductor or other hardware. This change in design has been of a precautionary nature rather than on account of any extensive trouble developed in the initial design.

Relay Settings

Since the protector tube normally clears a fault in approximately a half cycle, precautions must be taken in the relay setup to insure that high-speed relays do not initiate the tripping circuit during the period when the tube is carrying current. In the tube installations on the Philo-Newcomerstown and Newcomerstown-Canton lines, it was recognized that the relay setup was such that in heavy short circuits near Philo, there was a possibility of the trip circuit being set in action even with normal tube operation. However, to check the limit of low time to which these relays could be set, they were permitted to operate for two seasons with a minimum time of approximately one to $1^1/_2$ cycles. During the last two years, eight relay operations have taken place with perfect tube performance thus indicating that relay time is too short. Three of these occurrences took place in 1936 and five in 1937. However, no service interruptions were experienced. Positive indication that this low time setting of the relay was the cause of the outage was evidenced by the fact that the circuit did not trip at the opposite end.

Results of tests, not reported in detail here, indicate that successful tube operation has occurred even in three cycles. This indicates that a minimum relay time of something in the order of two to three cycles may be desirable on a circuit where tubes are installed. Another alternative may be the retention of one-cycle relaying and the use of ultra rapid reclosing.

Protector-Tube Current Ratings

To successfully interrupt short-circuit currents on the Philo-Canton line protector tubes, it was necessary to develop a tube of higher current rating than previously available. The design work, which was carried on prior to the instal-

Table I. Summary of 132-Kv Protector-Tube Installations

Line Designation	Length (Miles)	Number Towers	Number Tubes	Date Installed	Calculated Fault Amps* Max.	Calculated Fault Amps* Min.	Tube Rating (Amperes*) Max.	Tube Rating (Amperes*) Min.	Vents
Glenlyn-Roanoke	65	270	810	7/ 1/33	1960	660	2500	600	Angle†
					3990	1250	5000	900	
Roanoke-Fieldale	37	164	492	4/10/34	1960	660	2500	600	Straight
Fieldale-Danville	31	137	411	4/10/34	1350	700	2500	600	Straight
Philo-Newcomerstown	37	140	420	9/ 1/35	9400	1400	10000	1300	Angle
Newcomerstown-Canton	37	164	492	9/ 1/35	5100	1400	7500	1200	Angle
Turner-South Point	48	205	615	4/15/36	3160	1000	5000	900	Angle
					5830	1980	7500	1200	
Total	255	1080	3240						

† Straight vents prior to 1937. * Root-mean-square.

Table II. Protector Tube Operations,* Glenlyn-Roanoke 132-Kv Line
(Data From Physical Inspection)

		Fiber Tubes				Composite Tubes	
	Year	1933	1934	1935	1936	1937	Total
3-phase installations in service		270	270	270	270	270	
Equivalent single-phase installations in service		810	810	810	810	810	
Normal tube operations:	Top phase	1	14	10	35	30	90
	Middle phase	1	9	6	16	17	49
	Bottom phase	1	8	3	14	4	31
	Top and middle phases	2	8	1	10	6	27
	Top and bottom phases	1	5	3	8	5	22
	Middle and bottom phases	0	3	2	6	2	13
	Top, middle, and bottom phases	2	8	1	8	7	26
Total tubes		16	87	34	137	98	372
Total towers		9	55	27	97	71	259
Tube flashovers:	Top phase	0	5	2	9	2	18
	Middle phase	0	4	5	10	0	19
	Bottom phase	0	1	0	5	1	7
	Top and middle phases	0	0	1	0	0	1
	Top and bottom phases	0	0	0	0	0	0
	Middle and bottom phases	0	1	0	1	0	2
	Top, middle, and bottom phases	0	0	0	1	0	1
Total tubes		0	12	9	29	3	53†
Total towers		0	11	8	26	3	48

* Exclusive of tube target indications due to wind or vibration.
† Including two cases of tube flashover to tower.

Table III. Protector-Tube Operations,* Roanoke-Fieldale 132-Kv Line
(Data From Physical Inspection)

		Composite Tubes			With Shields	
	Year	1934	1935	1936	1937	Total
3-phase installations in service		164	164	164	164	
Equivalent single-phase installations in service		492	492	492	492	
Normal tube operations:	Top phase	12	2	20	15	49
	Middle phase	9	6	11	20	46
	Bottom phase	13	8	15	20	56
	Top and middle phases	5	0	8	7	20
	Top and bottom phases	1	0	2	12	15
	Middle and bottom phases	3	1	8	6	18
	Top, middle, and bottom phases	11	5	14	17	47
Total tubes		85	33	124	156	398
Total towers		54	22	78	97	251
Tube flashovers:	Top phase	0	3	1	2	6
	Middle phase	0	0	3	4	7
	Bottom phase	1	0	2	3	6
	Top and middle phases	0	0	0	0	0
	Top and bottom phases	0	0	0	0	0
	Middle and bottom phases	0	0	0	1	1
	Top, middle, and bottom phases	0	0	0	0	0
Total tubes		1	3	6	11	21
Total towers		1	3	6	10	20

* Exclusive of tube target indications due to wind or vibration.

Table IV. Protector-Tube Operations,* Fieldale-Danville 132-Kv Line
(Data From Physical Inspection)

		Composite Tubes			With Shields	
	Year	1934	1935	1936	1937	Total
3-phase installations in service		137	137	137	137	
Equivalent single-phase installations in service		411	411	411	411	
Normal tube operations:	Top phase	14	0	15	14	43
	Middle phase	8	0	7	15	30
	Bottom phase	8	0	13	8	29
	Top and middle phases	4	0	1	5	10
	Top and bottom phases	3	0	2	3	8
	Middle and bottom phases	7	0	1	4	12
	Top, middle, and bottom phases	4	0	9	8	21
Total tubes		70	0	70	85	225
Total towers		48	0	48	57	153
Tube flashovers:	Top phase	0	0	0	0	0
	Middle phase	0	0	0	0	0
	Bottom phase	0	0	0	0	0
	Top and middle phases	2	0	0	0	2
	Top and bottom phases	0	0	0	0	0
	Middle and bottom phases	0	0	0	0	0
	Top, middle, and bottom phases	0	0	0	0	0
Total tubes		4	0	0	0	4
Total towers		2	0	0	0	2

* Exclusive of tube target indications due to wind or vibration.

lation of tubes for the Turner-South Point and Philo-Newcomerstown-Canton lines, resulted in a tube with a maximum 60-cycle root-mean-square rating of 10,000 amperes. The field test of such a tube successfully discharging 17,800 crest amperes is shown in figure 3. The current record of such a tube discharging is given in the oscillogram of figure 4. Similar tests were reported previously on protector tubes before they were actually installed on the Glenlyn-Roanoke and Roanoke-Fieldale-Danville lines.[2,3]

Types of Tube Installations

The installations previously reported[3] utilized protector tubes mounted on the insulator assemblies with three types of construction. In one, the tubes on the insulator strings were of the so-called V type, in the other, of the parallel type, and in the third, of the 30-degree type but mounted on the structure. In the two more recent installations made on the Turner-South Point and Philo-Canton-Newcomerstown lines, the types of installations have all been of the V type. This procedure was followed due to the fact that the 30-degree type is not particularly desirable from a maintenance point of view as it clutters the tower structure rather badly. Further experience with the parallel and V types had up to that time shown no particular superiority of either, and since the V type was somewhat simpler to install, the decision was made to make the installation on this basis.

IV. Tube Performance

Performance of the tubes themselves under lightning conditions during the time they have been in service up to and including 1937 (excluding Turner-South Point for 1937 only) is given in tables II to VI, inclusive, for the six line sections listed in table I.

Before commenting on the contents of these tables, it should be pointed out that the initial installation of tubes on the Glenlyn-Roanoke line made in 1933 was replaced in 1937 with an improved de-

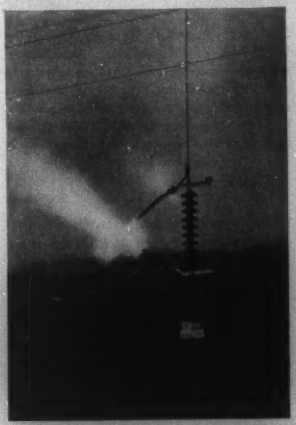


Figure 3. Field test of 1,300/10,000-ampere, 132-kv protector tube discharging satisfactorily 17,800 crest amperes in one-half cycle

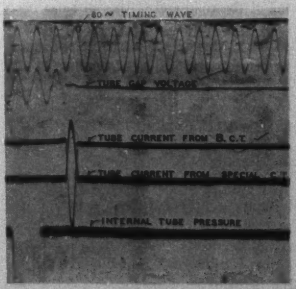


Figure 4. Protector-tube test successfully interrupting 17,150 crest amperes in one-half cycle. This type of tube now in service on Philo-Canton 132-kv line. (Field test November 15–17, 1934—internal tube pressure measured as approximately one ton per square inch)

Table V. Protector-Tube Operations,* Philo-Newcomerstown 132-Kv Line
(Data From Physical Inspection)

		Composite Tubes			
	Year	1935	1936	1937	Total
3-phase installations in service		140	140	140	
Equivalent single-phase installations in service		420	420	420	
Normal tube operations:	Top phase	0	20	17	37
	Middle phase	0	3	9	12
	Bottom phase	0	1	2	3
	Top and middle phases	0	1	4	5
	Top and bottom phases	0	0	2	2
	Middle and bottom phases	0	1	0	1
	Top, middle, and bottom phases	0	2	4	6
Total tubes		0	34	52	86
Total towers		0	28	38	66
Tube flashovers:	Top phase	0	1	0	1
	Middle phase	0	0	0	0
	Bottom phase	0	0	0	0
	Top and middle phases	0	0	0	0
	Top and bottom phases	0	0	0	0
	Middle and bottom phases	0	0	0	0
	Top, middle, and bottom phases	0	0	0	0
Total tubes		0	1	0	1
Total towers		0	1	0	1

* Exclusive of tube target indications due to wind or vibration.

Table VI. Protector-Tube Operations,* Newcomerstown-Canton and Turner-South Point 132-Kv Lines
(Data From Physical Inspection)

		Newcomerstown-Canton, Composite Tubes				Turner-South Point
	Year	1935	1936	1937	Total	1936
3-phase installations in service		164	164	164		205
Equivalent single-phase installations in service		492	492	492		615
Normal tube operations:	Top phase	0	13	22	35	14
	Middle phase	0	8	10	18	6
	Bottom phase	0	1	5	6	6
	Top and middle phases	1	6	3	10	5
	Top and bottom phases	0	2	1	3	2
	Middle and bottom phases	0	2	0	2	0
	Top, middle, and bottom phases	0	2	3	5	4
Total tubes		2	48	54	102	37
Total towers		1	34	44	79	52
Tube flashovers:	Top phase	0	0	0	0	0
	Middle phase	0	0	0	0	0
	Bottom phase	1	0	0	1	0
	Top and middle phases	0	0	0	0	0
	Top and bottom phases	0	0	0	0	0
	Middle and bottom phases	0	0	0	0	0
	Top, middle, and bottom phases	0	0	0	0	0
Total tubes		1	0	0	1	0
Total towers		1	0	0	1	0

* Exclusive of tube target indications due to wind or vibration.

Table VII. Performance of Flashed-Over Protector Tubes

Tube Operation	Glenlyn-Roanoke	Roanoke-Fieldale	Fieldale-Danville	Total
Tubes with one flashover	51	20	4	75
Tubes with two flashovers	1	1	0	2
Tubes with: one normal operation before flashover	7	4	0	11
two normal operations before flashover	0	6	0	6
one normal operation after flashover	5	2	2	9
two normal operations after flashover	0	0	0	0

sign of tube. The initial tubes were all fiber and had reached the end of their useful life at the end of four years. Since it was found that the fiber, when exposed without protection to the weather, had experienced serious deterioration, the new tube installation on this line, as well as all other tubes now in service on the 132-kv system, have the improved waterproof Textolite covering. In the analysis that follows, therefore, it should be borne in mind that the performance of the Glenlyn-Roanoke line during 1936, when the all-fiber tubes were reaching the end of their useful life, is somewhat worse than would be expected from more modern design tubes even in only reasonably good condition. The data in the tables definitely indicate that tube deterioration on the original tubes had become serious by 1936.

Of the 810 tubes in service on the Glenlyn-Roanoke line during the past five years, there has been a total of 372 successful tube operations, 51 tube flashovers, and 2 tube failures where internal pressure burst the tube (table X). On a percentage basis this gives 87.1 per cent successful tube operations, 12.4 per cent flashovers and 0.5 per cent failures. However, if the high flashover record of 1936, when the all-fiber tubes had badly deteriorated is omitted, the record shows 93 per cent successful operations, 6 per cent flashovers and 0.5 per cent failures.

Of the 492 tubes in operation on the Roanoke-Fieldale line (table III) 398 normal operations occurred during the four-year period. There were 21 tube flashovers and one tube failure. This performance can be stated on a percentage basis as 94.8 per cent successful operations, 5 per cent tube flashovers, and 0.24 per cent tube failures. On the Fieldale-Danville line where 411 tubes were installed 98 per cent of the tube operations were successful and two per cent resulted in tube flashovers. There were no tube failures on this line in four years' operation. As the tube type, rating, age, and method of installation were identical on the two above lines (Roanoke-Fieldale and Fieldale-Danville) the difference in tube performance can be accounted for only on the basis of frequency and severity of lightning conditions encountered.

The record of tube operations on the Philo-Newcomerstown, Newcomerstown-Canton, and Turner-South Point lines (tables V and VI) was much better. For these three lines there have been two flashed-over tubes in addition to 123 successful operations, and two ruptured tubes. This gives 97 per cent successful operations, 1.5 per cent tube flashovers and 1.5 per cent tube failures.

It will be noted in general that a very much better performance is indicated on the Fieldale-Danville, Philo-Newcomerstown, Newcomerstown-Canton, and Turner-South Point lines than was obtained on the initial installation of tubes on the Glenlyn-Roanoke line where the all-fiber tubes were used. It is believed that this better performance is due in part not only to the comparatively short time the tubes have been in service (two to three years) but also to the improvements in design on the newer tubes worked out in the period elapsed between the instal-

Table VIII. 132-Kv Protector Tubes Disrupted in Service (1933 to 1937, Inclusive)

Ref.	Line	Year	Phase	Tube Location	Line Tripout	Remarks
8R	G-R	8/ 8/37	Middle	Line	No.	Tube ruptured. Top and bottom phase tubes operated O.K. Tower current 10,300 amperes. Ground-wire current 17,700 amperes.
1R	G-R	6/17/37	Middle	Ground	No.	Tube ruptured. Severe lightning. No other tubes operated. No tower current.
113	R-F	9/10/36	Middle	Line	?	Tube ruptured. Top phase tube operated O.K. Bottom phase tube flashed over.
246	N-C	8/21/36	Top	Ground	No.	Tube blown off. Fiber threads stripped.
6	P-C	8/25/36	Top	Line	No.	End of tube blown off.

Table IX. 132-Kv Protector Tubes Having Repeated Operations (Normal and Flashover)
(Observed by Target Indication)

Number of Tube Operations	Glenlyn-Roanoke		Roanoke-Fieldale		Fieldale-Danville		Total	Average
	Number	Per Cent	Number	Per Cent	Number	Per Cent	Number	Per Cent
2	63	12.4	79	16.0	42	10.2	184	12.9
3	13	1.6	14	2.9	2	0.5	29	1.7
4	8	1.0	1	0.2	0	0	9	0.4
5	0	0	0	0	0	0	0	0
Years operation	5		4		4			

lation on the Glenlyn-Roanoke line and these installations.

An analysis of the performance of the flashed-over tubes, made in table VII shows that out of 75 tubes which flashed over, 11 or 13.7 per cent experienced only one normal operation before flashover. Six or eight per cent experienced two normal operations before flashover. Further analysis shows that nine tubes or 12 per cent underwent one normal operation before external flashover had occurred. The above operations are, of course, those noted by target indication and may have actually been somewhat greater due to the possible occurrence of multiple strokes.

Tubes Blown up in Service

When initially applying protective tubes for line protection, the possibility of tube failure due to exceedingly high lightning currents and to 60-cycle currents either above or below the tube rating was considered. As pointed out in table I, the 60-cycle maximum and minimum short-circuit currents of each line were calculated, and tubes selected to cover the range of 60-cycle currents expected. It is gratifying, as will be seen from table VIII, that the record of exploded or blown-up tubes for all lines during the entire time when tubes have been in operation, totals only five, and that of these five tube failures, four resulted in no line tripout, and there is no absolute certainty that a line tripped out even in the fifth case. The experience cited, therefore, seems to indicate that the tubes have been applied within their actual rating, and that the tubes have the ability to safely interrupt 60-cycle currents that can reasonably be demanded of them. Trouble from excessive lightning stroke currents disrupting a tube and producing a line outage appears, from records so far obtained, to be negligible.

Repeated Operation of Tubes

The number of times a tube may be called upon to interrupt currents in service must be considered in estimating the life of the tube. To throw some light on this situation, multiple operations recorded on the tubes from physical inspection of targets in the field have been analyzed and are given in table IX. This record shows that during the five-year period of operation studied here, 184 tubes have operated twice, 29 tubes three times, 9 tubes four times, and none five times or more.

As pointed out under "Multiple Strokes" discussed later, additional duty

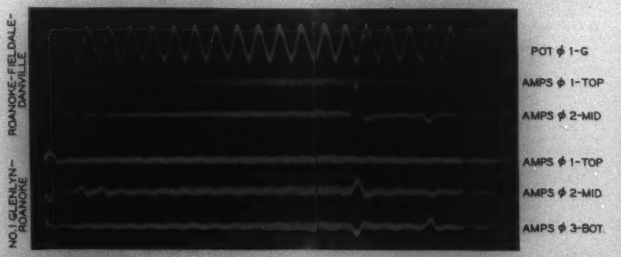


Figure 5. Multiple lightning stroke (five strokes in eighteen cycles) cleared successfully by protector tube. (Oscillogram number 20—June 18, 1937—1:05 p.m.—stroke to Roanoke-Fieldale-Danville 132-kv line.) Note reversal of line polarity at instant of strokes

Figure 6. Multiple lightning stroke (three strokes in 13½ cycles) which developed into line fault (Oscillogram number 36—July 10, 1937—4:45½ p.m.). Stroke to Roanoke-Fieldale-Danville 132-kv line

Table X. Line Outages Caused by Lightning on Tube-Equipped 132-Kv Lines Before and After Tube Installation

	Glenlyn-Roanoke	Roanoke-Fieldale*	Fieldale-Danville*	Philo-Newcomerstown**	Newcomerstown-Canton**	Turner-South Point
Length of line (miles)	65	37	31	37	37	48
Years in service without tubes	6	7	7	11	11	1
Years in service with tubes	5	4	4	2	2	2
Lightning outages:						
1927	16	9.5	7.9	1	1	—
1928	4	7.6	6.3	3.5	3.5	—
1929	23	12.1	10.1	3	3	—
1930	10	17.5	14.5	1.5	1.5	—
1931	22	13.3	11.3	3.5	3.5	—
1932	4	4.5	3.8	1.5	1.5	—
1933	0†	9.7	8.1	2.5	2.5	—
1934	9	1	2	6	6	—
1935	5	3	1	7	6	2††
1936	28	7	1	2	1	1¶
1937	4	12	0	1	2	0
Outages per 100 miles of line per year without tubes	20.0	29.0	29.0	8.86	8.56	4.16
With tubes	14.2	15.0	3.2	4.1	4.1	1.04
Ratio: with tubes to no tubes	0.71	0.52	0.11	0.46	0.47	0.25
Ratio: average of six lines	—	—	0.42	—	—	—

* Outages prorated 1927–1933 when part of Roanoke-Roxboro line. ** Outages prorated 1927–1935 when part of Philo-Canton line. † Three outages occurred before tubes were installed July 1, 1933. †† In service seven months. ¶ Tripped at one end only; relays set for three cycles.

Table XI. Lightning Outages on Two-Circuit Lines With and Without Tubes on One Line

	Philo-Newcomerstown-Canton			Glenlyn-Roanoke		
Year	Tube Circuit (Total)	Nontube Circuit (Total)	Both Circuits (Only)	Tube Circuit (Total)	Nontube Circuit (Total)	Both Circuits (Only)
1927	2	3	1	16	13	3
1928	7	7	2	4	5	2
1929	6	7	2	23	17	10
1930	3	4	3	10	6	5
1931	7	6	5	22	23	15
1932	3	4	2	4	4	2
1933*	5	5	4	3†	5	2†
1934	12	21	8	9	8	1
1935**	13	13	6	5	4	2
1936	3	4	0	28	19	8
1937	3	9	0	4	6	0
Tripouts per 100 miles of line per year: without tubes	8.7	10.5	5.0	20.0	17.2	9.4
with tubes	4.1	8.8	0	14.2	13.0	3.4
Ratio: with tubes to no tubes	0.48	0.84	0	0.71	0.76	0.36

* Tubes installed on Glenlyn-Roanoke line July 1, 1933. ** Tubes installed on Philo-Newcomerstown-Canton line September 1, 1935. (One tripout on tube line after this.) † These tripouts occurred before tubes were installed.

is placed on the tube by the multiple stroke. The above data give, however, fairer indications of how many times lightning may be expected to occur at a given location than they indicate how many times a particular tube may be called upon to operate. For example, if a tube is subjected to the effect of four lightning strokes in a five-year interval, and these are multiple strokes each time and the multiple stroke has, say seven successive discharges, the tube would, of course, be subject to 28 discharges during the five-year interval. From the fact that only five tubes have been completely disrupted by internal pressure in the five-year experience cited herein, and four of these tubes failed (perhaps under conditions of direct lightning stroke) it seems quite evident that our experience to date does not indicate that sufficient internal erosion can be expected in the tubes, in four years at least, to become a serious hazard to their life or performance.

V. Line Outage Record

While the performance of the tube itself, that is, its ability to interrupt 60-cycle or lightning currents without damage to itself or without external flashover is important, it must not be forgotten that the ultimate goal of the tube is protection of the line from flashover or tripout. It is therefore of paramount interest to study the record of the tube-equipped lines both before and after the tubes were applied.

The outage record of the six line sections previously referred to is given in table X from 1933 (or date of line installations) to 1937, inclusive. The record of outages on a 100-mile-per-year basis both before tubes were installed and after are given in the lower part of the table. It will be noted that the line outages range from ten per cent to 70 per cent of the outages on the same lines prior to tube installation. Such a comparison, of course, should include an evaluation of the lightning severity and frequency during the period under comparison, two factors which are difficult to evaluate. In general, however, it will be noted that the reduction in outages made averages well over 50 per cent when tubes are used.

While the performance of the protector tube is to prevent line outages, it is also true that when installed on one circuit of a double-circuit line where one circuit only is sufficient to carry the load momentarily during an interruption, the number of double-circuit outages is a major basis on which to judge the tube performance. It will be noted in table XI that in the two-circuit lines involved (Philo-Newcomerstown-Canton and Glenlyn-Roanoke) the two-circuit outages have, for a two-year period, been entirely eliminated on the Philo-Newcomerstown line and have been reduced to 36 per cent on the Glenlyn-Roanoke line. Excluding 1936 when the Glenlyn-Roanoke tubes had deteriorated, the double-circuit outages on this line averaged 1.25 per year for a four-year period or 13.3 per cent of the average double-circuit outages before tubes were installed. Another point of interest in this table is that the outages on the nontube-equipped line in each case have likewise been reduced in the order of 16 to 24 per cent. While the periods analyzed are comparatively short, particularly in the case of the Philo-Newcomerstown-Canton line and it may therefore not be representative of what can be expected over a long period of time, it appears, however, that the tube-equipped line has reduced the number of outages on the nontube line. It is quite reasonable to expect this as well as a reduction in double-circuit outages.

VI. Multiple Strokes

During the time that the protector tubes were in service on the Glenlyn-Roanoke line, an investigation on this line jointly conducted with the General

Electric Company has produced some interesting data on the lightning conditions under which protector gaps are required to operate. A crater-lamp oscillograph[8] was installed at Roanoke for the past four years and many records of the tube performance were obtained thereby. The summarized data on multiple lightning strokes as obtained by the crater-lamp oscillograph in conjunction with protector-gap operations is shown in table XII. It will be noted that successive strokes in one lightning discharge range from two or seven. The polarity of the conductor when line fault is initiated, that is, when lightning presumably strikes, might be expected to be predominantly positive on the basis that some 90 per cent or more of observed lightning strokes to line are of negative polarity. The record in table XII shows that of 300 faults, including single and multistroke faults, in 59 per cent of the cases, the faulty conductor is positive, in 34.5 per cent they are negative, and in 6.5 per cent of the cases, the conductor is near zero potential. Even with the multiple stroke there is no consistency shown in the stroke occurring successively to the conductor or to the conductors which are positive. The conclusion may be drawn therefore although the tendency to be struck is much greater when the line is positive than when it is negative, nevertheless when lightning is ready to strike the line, it often strikes irrespective of the 60-cycle polarity of the line wires.

VII. Conclusions

From the data presented above based on five years of operation in service, and other records and related information too voluminous to present and discuss here, the following conclusions seem justified:

1. Protector tubes, when applied within their rating, appear able to operate without mechanical rupture under all but a few infrequent currents encountered on a transmission system. Even when rupture occurs the faulted line may not and generally will not trip out.

2. Internal tube erosion, as an agent in reducing the current interruption capacity of the tube has not, in five years' operation, appeared as a factor limiting the tube life.

3. The multiple lightning stroke is a factor tending to shorten the tube life of the tube. However, rapidly recurring discharges in a multiple stroke have been successfully interrupted by the tube (three discharges in three cycles have been interrupted satisfactorily).

4. In applying tubes for line protection considerable care should be given to adequate disposal of the discharge gases. Two cases were found where the tubes had apparently flashed to the tower as a result of improper dispositions of gases. Several cases of slightly pitted conductors have also been observed where the gases were expelled directly onto the line conductors.

5. The operation of tube life is still an incompletely solved problem. From a weighing of the present knowledge concerning the theory and performance of tubes it would appear that life depends largely on the weathering qualities of the exterior of the tube covering or surface.

6. The weathering qualities of the tube, and their relation to the tube protective features need further study and investigation. It is suggested that the rate of system recovery voltage may be closely related to this aspect of the problem.

7. Relays on tube-protected lines should either have a definite minimum time to

Table XII. Polarity of Phase Potential at Occurrence of Fault

Multiple Strokes to Roanoke-Danville Circuit

| | 1934 | | | | | | | | | | | | | | | | | | | | | | | | | 1935 | | | | | | | | | | | | | | | | | | |

initiate the oil circuit breaker trip circuit of not less than two to three cycles, or as an alternative, when using one cycle relaying, breakers should utilize ultrarapid reclosing.

8. When properly applied the tube protects the line insulators against lightning flashover. No flashovers of insulator strings protected by tubes has so far been observed.

9. Protector tubes have reduced line outages over 50 per cent on the average and show a reduction as high as 89 per cent in the case of one line.

10. Reductions in service outages on two-circuit lines of over 85 per cent have been obtained by equipping only one line with tubes (omitting the one year's experience, 1936—on the Glenlyn-Roanoke line when the initial design tube had become defective).

11. On two-circuit lines, with one line tube-equipped, outages on the nontube line have been reduced by from 15 to 25 per cent.

Acknowledgments

The authors wish to acknowledge the assistance of G. D. Lippert of the American Gas and Electric Service Corporation in compiling and correlating data in the paper, and the co-operation of the staffs of the Appalachian Electric Power Company and The Ohio Power Company in supplying field records of tube operation.

Bibliography

1. An Experimental Lightning Protector for Insulators, **J. J. Torok**. AIEE Lightning Reference Book, pages 928–30.

2. Expulsion Protective Gap, **K. B. McEachron, I. W. Gross, and H. L. Melvin**. AIEE Lightning Reference Book, pages 1188–95.

3. Expulsion Protective Gaps on 132-Kv Lines, **Philip Sporn and I. W. Gross**. AIEE Lightning Reference Book, pages 1461–8.

4. Lightning Performance of 132-Kv Lines (1932–33), **Philip Sporn and I. W. Gross**. AIEE Lightning Reference Book, pages 1297–1302.

5. Multiple Lightning Strokes, **K. B. McEachron**. AIEE Lightning Reference Book, pages 1253–7.

6. The Crater Lamp Oscillograph, **McMorris, Rusher, Hagenguth**. *General Electric Review*, November 1934, pages 514–16.

7. The Dehion Flashover Protector and Its Application to Transmission Lines, **A. M. Opsahl and J. J. Torok**. AIEE Lightning Reference Book, pages 1185–7.

8. Lightning Investigation on a Wood Pole Transmission Line, **R. R. Pittman and J. J. Torok**. AIEE Lightning Reference Book, pages 871–5.

9. Effect Which Different Distributions of Expulsion Gaps Have on Direct-Stroke Protection of Transmission Lines, **L. V. Bewley**. AIEE Lightning Reference Book, pages 1480–5.

10. Protecting Transmission Lines Against Lightning, **W. W. Lewis**. *General Electric Review*, July 1937, pages 314–18.

11. Protection of Stations Against Lightning, **L. V. Bewley and W. J. Rudge, Jr.** *General Electric Review*, August 1937, pages 363–71.

12. Expulsion Protective Gaps, **Rudge and Wade**. AIEE Transactions, 1937, pages 551–7.

13. Recovery Voltage Characteristics of Typical Transmission Systems and Relation to Protector-Tube Application, **Evans and Monteith**. AIEE Winter Convention, 1938.

14. Ultrahigh-Speed Reclosing of High-Voltage Transmission Lines, **Philip Sporn and D. C. Prince**. AIEE Transactions, 1937, pages 81–90.

Discussion

E. J. Allen (General Electric Company, Pittsfield, Mass.): The authors are to be commended for a most comprehensive summary of 132-kv protector-tube operation. The large amount of operating experience accumulated and presented in this paper represents a total of over 10,000 tube-years of service.

Figure 1 of the paper shows the grading shields applied to the protector tubes on both the Roanoke-Fieldale and Fieldale-Danville lines just prior to the 1937 lightning season, as a means of reducing external tube flashovers due to lightning. Table III indicates 11 tube flashovers in the 1937 lightning season, whereas there were 6 in 1936 before the shields were added. It is therefore of interest to analyze this relationship.

Analysis shows that there are two types of protector-tube mountings on these lines; one the V mounting and the other the parallel mounting. These mountings were described in a previous paper[1] by the authors. With grading rings on the parallel-mounted tubes in 1937, no external flashovers occurred except in one questionable instance. Out of 450 parallel-mounted tubes equipped with shields in 1937, 113 normal operations were recorded. Most of the parallel-mounted tubes, or 73.5 per cent, are located on the Fieldale-Danville section, where no external flashovers were reported.

The 11 external flashovers listed in table III for the Roanoke-Fieldale line, however, occurred entirely on the V-mounted tubes. Eighty-two per cent of the V-mounted tubes are located on the Roanoke-Fieldale line, where the external flashovers were reported.

Analysis of reported flashovers shows that 8 out of the 11 external flashovers classified in table III were apparently not external tube flashovers. In all 8 cases where this was believed to have occurred, the single suspension V-mounting, as shown in figure 1, was installed. Targets located on the lower (line end) tubes had operated in every case, and hence the tubes must have discharged internally. The flashover occurring subsequently was probably due to discharge gases from the upper tube improperly contacting the line. The design of tube shown in figure 2 with gas deflector readily overcomes this difficulty. On this basis there would have occurred not more than three external tube flashovers on the Roanoke-Fieldale line in 1937, where grading rings are installed. As table III will show, this is a 50 per cent reduction as compared with the 1936 season, although in 1937 the tubes were called upon to operate 36 per cent more frequently.

The field data on repeated operations and multiple strokes presented in the paper, indicate that the chances of any individual tube having a large number of repeated operations is remote. Except in possibly a limited number of cases where unusually high line exposure to lightning exists, this is in agreement with conclusion 2 of the paper.

Moreover, on lines having an unusually high impulse spark-over level, advantage can be taken of the surplus margin of protection offered by the tube in order to reduce the number of tube operations to a minimum. This is accomplished by increasing the protector tube series gap setting above normal, so that the impulse spark-over is also increased.[2] Care should be taken, however, to allow not less than 20 per cent margin of impulse protection to the line insulation. By this procedure, the lesser magnitude surges would not cause unnecessary tube operations, but at the same time, the protection level of the tube would be adequate to prevent insulator flashovers or outages. For the first few structures out from stations, however, it is probably desirable to retain the normal series gap settings in order to minimize the magnitude of impulse waves entering the station.

As the authors point out, the principal objective of protector tubes is the protection of a line from lightning flashover and resultant line outage. Table X shows protector tubes have reduced line outages over 50 per cent on the average, with a reduction as high as 89 per cent in the case of one line. It is particularly significant that 132-kv protector tubes of modern design installed on one circuit of the Philo-Newcomerstown-Canton line, a distance of 74 miles, double circuit outages have been entirely eliminated over a two-year period. Prior to the installation of protector tubes on the one circuit, this line had an average of 3.66 double circuit outages per year over the preceding nine years.

References

1. Expulsion Protective Gaps on 132-Kv Lines, **Philip Sporn and I. W. Gross**. Electrical Engineering, January 1935, pages 66–73.

2. Expulsion Protective Gaps, **W. J. Rudge, Jr. and E. J. Wade**. Electrical Engineering, May 1937, pages 551–7.

K. B. McEachron (General Electric Company, Pittsfield, Mass.): One might infer from the last sentence of the section entitled "Multiple Strokes" that the polarity of the line might be expected to have some control over which conductor would be struck. There seems to be no good justification for such a point of view. Rather, it is assumed that as a rule the ground wire will be struck, but which tube operates as the tower potential rises is determined to a considerable degree by conductor polarity at that instant.

Table XII shows all of the data plotted with respect to polarity of the protector-tube follow current. Considering the successive discharges of a multiple stroke as a single discharge, follow current occurred 178 times when the conductor involved was positive, 102 times when it was negative, and 20 times when the potential was recorded as zero. The per cent positive, negative, and zero are 59.8, 33.5, and 6.7.

Considering only those discharges which involved but one phase, it is found from table XII of the paper that 50 times the polarity of the follow current was positive and 12 times it was negative. This is shown in table I.

The number of successive discharges as shown in figure 4 vary up to 12 as a maxi-

Table I. Polarity of Follow Currents When One Phase Only Is Involved

Phase Involved	Polarity of Follow Current for Multiple Strokes: Positive	Multiple Strokes: Negative	Single Strokes: Positive	Single Strokes: Negative	Total per Phase
1	9	3	15	2	29
2	10	2	7	4	23
3	4	1	5	0	9
Total	23	6	27	6	

mum. Sixteen per cent of all the strokes and 61 per cent of the multiple strokes consisted of at least three discharges, while 4 per cent of all strokes and 15 per cent of the multiple strokes had at least five discharges.

Lewis and Foust[1] have found that of 358 strokes recorded during the years 1934, 1935, and 1936 through tower legs of transmission lines, approximately 95 per cent were negative. Sufficient data are now available both from the present investigation and in the laboratory,[2] so that it is quite certain that the most positive conductor will in general flashover first with a negative impulse applied to the tower or ground wire. This follows since the impulse and the system potential to ground at that instant are additive if the impulse is applied to the tower end of the insulator string.

Perhaps the fact that 95 per cent of the strokes are negative, while but 81 per cent of the follow currents with one phase involved are positive, is partly explained by the possibility of a small but unknown number of strokes to line conductors rather than to the ground wire. From table XII, it is found that phase 1 had 24 positive and 5 negative follow currents when but one phase was involved, phase 2 had 17 positive and 6 negative, while phase 3 had 9 positive and 1 negative follow currents. The top and bottom phases, which are phases 1 and 3, had 83 per cent and 90 per cent positive follow currents, while the corresponding figure for the middle phase was 74 per cent. This might indicate that the middle phase conductor was struck more frequently than the others. However, the data are not sufficiently good to draw such a conclusion definitely.

According to Bewley,[3] the coupling factor between the ground wire and the line conductors would be 0.278, 0.205, and 0.160 for the top, middle, and bottom conductor. On this basis, one would expect the bottom protector gap to operate first, since the coupling is only a little more than half that of the top conductor.

However, the data show that the top conductor (table I of this discussion) had single follow currents involving one phase only 29 times, while the middle and bottom conductors were involved 23 and 9 times, respectively. If it is assumed that negative follow currents mean strokes to the conductor when but one phase is involved, and further assumed that as many strokes occurred to the single conductor when positive as when negative, it might be inferred that the top phase conductor was struck 10 times, the middle conductor 12 times, and the lower conductor 2 times. On this basis, the ground wire was struck 27 times, considering the data of table I. This sort of analysis represents considerable speculation, and is probably pessimistic with respect to the number of times the ground wire was struck.

Another factor which ought to be mentioned is the effect of distance to ground. The ground ends of the insulators on the top phase are approximately 25 feet further from ground than the bottom conductors, which of course acts to increase the potential across the top expulsion protector tube compared with the others, and might be of importance if the applied wave were steep enough.

Number of Conductors Involved

If the number of phases which carry impulse current as a result of protector tube operation is an indication of the amount of current in the stroke, then the data given in table II seem to show that the multiple stroke is likely to contain more current than the single stroke, since of the discharges of the multiple strokes 35.7 per cent involved one phase, while 39.8 per cent involved two phases, and 24.5 per cent all three phases. The corresponding percentages for the single discharges are 52.3 per cent single phase, 37.0 per cent two phases, and 10.7 per cent three phases. Only 3 out of 13 multiple strokes, in which three conductors were involved simultaneously, began with less than three tubes operating at once. This seems to indicate, based on these data, that the first discharge of the multiple stroke is likely to carry current at least equal to or greater than that in the succeeding discharges.

References

1. Lightning Investigations on Transmission Lines—VI, W. W. Lewis and C. M. Foust. Electrical Engineering, January 1937, page 101.

2. Multiple Lightning Strokes, K. B. McEachron. AIEE Transactions, 1934, page 1633.

3. Protection of Transmission Lines Against Lightning—Theory and Calculations, L. V. Bewley. *G. E. Review*, April 1937, page 180.

E. J. Wade (General Electric Company, Pittsfield, Mass.): The paper by Messrs. Sporn and Gross is a valuable addition to the field data on the performance of protector tubes. An attempt will be made in the present discussion to show that the data seem to indicate a definite relation between the number of expulsion tube operations and tower ground resistance, and also that the number of tubes which had repeated operations is in close agreement with the number which would be predicted, based on the theory of probability, which allows an estimate to be made regarding the number of discharges through tubes due to multiple strokes.

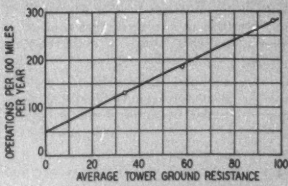


Figure 1. Effect of tower ground resistance on expulsion-tube operations

Examining first the effect of ground resistance, figure 1 of this discussion has been plotted to show the relation between average ground resistance and the number of tube operations per year for the Glenlyn-Roanoke and Roanoke-Danville lines. Since there is a definite difference in the ground resistance of the two halves of the Roanoke-Danville line, the two sections on either side of Fieldale have been considered separately.

As shown on the graph, these data may be well represented by a straight line passing through approximately 50 operations per 100 miles per year at zero tower resistance. If this interpretation is accepted, it means that the difference in the number of tube operations on the two halves of the Roanoke-Danville line is due to variation in ground resistance and not to a difference in lightning severity as suggested in the paper. Where the resistance is higher there is more tendency for adjacent tubes to operate and less stroke current is required to cause operation at the tower which is struck. The point of intersection with the ordinate at zero tower resistance may be an indication of the number of strokes which contact the line conductors. A similar analysis was made with regard to strokes contacting the line conductors and the relation between ground resistance and insulator flashovers in a discussion by S. M. Zubair (Electrical Engineering, volume 55, pages 277–9).

Considering the number of tubes which may be expected to operate more than once, and assuming that any tube on the circuit is equally likely to be struck, regardless of whether or not it has previously operated, then the law of independent trials will apply. This is closely approximated by Poisson's law which may be written:

$$P_m(n) = \frac{e^{-mp}(mp)^n}{n!}$$ the chance which a given tube has of being hit n times in m trials

p = chance that a particular tube will operate on any one stroke

$$= \frac{1}{\text{number tubes installed}}$$

Table II. Probability Calculations

Line	Number Tubes Installed		Tube Operations: One	Two	Three	Four	Period (Years)
Glenlyn-Roanoke	810	Calculated	251	66	11.5	1.5	5
		Field	228	63	13	.8	5
Fieldale-Danville	411	Calculated	130	35.5	6.5	0.9	4
		Field	139	42	2	0	4
Roanoke-Fieldale	492	Calculated	178	71	19.2	3.9	4
		Field	215	79	14	1	4

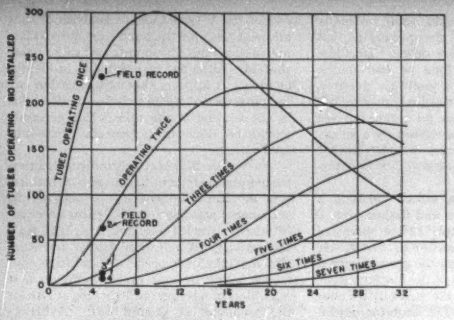


Figure 2. Probability calculation for expulsion tubes operating on Glenlyn-Roanoke line (neglecting multiple strokes)

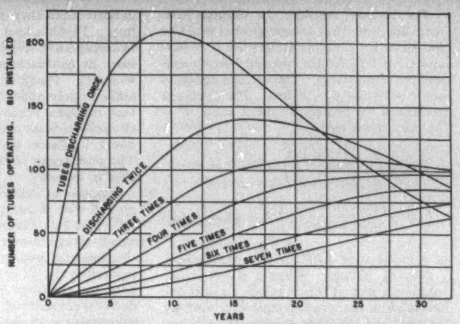


Figure 3. Probability calculation for expulsion tubes operating on Glenlyn-Roanoke line (including multiple strokes)

n = number of times each tube operates

m = total number of operations of tubes for the period being considered

Applying this to the Roanoke lines using the data from tables II, III, and IV of the paper, the results shown in table II of this discussion are obtained. The good agreement which is shown with the field data indicates that tube operations follow rather closely the probability law. The reason for the increasing discrepancy as the number of operations per tube increases is probably due to a few places on the lines which have unusually high exposure. This calculation is shown in figure 2 of this discussion carried out to a period of 32 years. It will be seen that the number of tubes which had six or seven repeated operations is very small even after a long period.

These calculations may be taken as an indication of the number of tubes which would operate on a line passing over level country where the storms are equally distributed. Of course this represents the most optimistic conditions as any line would have some degree of unequal exposure. However, the calculated values check fairly well with the data from the Roanoke lines which are over mountainous territory which indicates that no great discrepancies may be expected.

It is of interest to extend this calculation to include the number of discharges through tubes due to multiple strokes. Mr. McEachron's paper shows that approximately 30 per cent of the strokes over a period of years consist of more than one discharge, 14 per cent of two discharges, 8 per cent of three, 4 per cent of four, 2 per cent of five, and the remaining 2 per cent of six or more.

The probability that a tube will have a certain number of discharges during a given time is the sum of the probabilities of each of the various combinations of single or multiple strokes which can produce the assumed number of discharges.

For instance, three discharges may be obtained by three combinations, namely,

Three "single" strokes,

One "single" and one "double" stroke,

One "triple" stroke.

Similarly, for four discharges there are five combinations, for five discharges seven combinations, etc.

The probability of obtaining each of these combinations is found by taking the product of the probabilities for their components together with the probability of not obtaining any additional discharges.

The results of this calculation are shown by figure 3 and it appears that the chance of an excessive number of tube operations under conditions of equal exposure either due to successive hits or to multiple strokes is very small, since on the average the operations will be rather evenly distributed over the total number of tubes. However, there may be a few cases of tubes having an excessive number of operations due either to multiple strokes or to high ground resistance or to locations of excessive exposure.

As a result of this study, excessive erosion due to a large number of tube operations, is very unlikely except in a very limited number of cases. This agrees with conclusion 2 of the paper.

L. V. Bewley (General Electric Company, Pittsfield, Mass.): The data presented in this paper show that the protector tubes on the top conductors operate more frequently than those on the bottom conductor, in spite of the fact that the line is equipped with a ground wire, and therefore the coupling is materially more for the top than for the bottom conductor, being 0.30 and 0.17 per cent respectively. Such behavior also appears to be typical of insulator flashovers on lines equipped with ground wires.[1] There are possibly four explanations for such behavior:

Inadequate Shielding. By *shielding* is meant ground wires sufficiently high and properly placed so as to intercept the lightning stroke and prevent termination on the line conductors. If the ground wire or wires are not adequate in this respect, a certain percentage of the lightning strokes will evade the ground wires and contact a line conductor. If this occurs, it is the top or middle conductor most likely to be struck. Zubair[2] has plotted flashovers as a function of tower footing resistance, and by extrapolating the curve to zero footing resistance has found the number of flashovers independent of footing resistance. He assigns, as the reason for these flashovers, direct strokes to the line conductors; and arrives at a "shielding efficiency." In the case of the Glenlyn-Roanoke line the shielding efficiency is 0.77, that is 22 per cent of the strokes contacted the line conductor.[1] Of course some of these flashovers independent of footing resistance may have been due to midspan flashover rather than to inadequate shielding.

Tower Gradient. McEachron has suggested in his discussion that tower gradients may overcome the difference in coupling effect and impose flashover on the top conductor. Calculation shows, however, that a rather high gradient would be necessary to accomplish such a result. Let:

E = instantaneous voltage at top of tower and on ground wire

x = vertical distance from top of tower to top conductor

y = vertical distance between top and bottom conductor

C = coupling factor with top conductor

C' = coupling factor with bottom conductor

G = gradient down tower in kilovolts per foot

Then the voltages across the top and bottom insulators are respectively:

$$V = E - Gx - CE = E(1 - C) - Gx \quad (1)$$

$$V' = E - G(x + y) - C'E = E(1 - C') - G(x + y) \quad (2)$$

The difference in voltage is

$$V' - V = E(C - C') - Gy \quad (3)$$

Solving (1) for E and substituting in (3) there results

$$V' - V = (V + Gx)\left(\frac{C - C'}{1 - C}\right) - Gy \quad (4)$$

The gradient necessary to overcome the differential in coupling is that for which $(V' - V) = 0$, and (4) gives

$$G = V\left(\frac{C - C'}{1 - C}\right) \div \left(y - \frac{C - C'}{1 - C}x\right) \quad (5)$$

where V is now the insulator (or protector tube) flashover kilovolts of the top conductor.

For example, consider the Glenlyn-Roanoke line which has a single ground wire and for which the coupling factors are $C = 0.30$ and $C' = 0.17$ for the top and bottom conductors respectively. The vertical distances are $x = 10$ and $y = 26$ feet. The discharge voltage of the protector tube is about $V = 700$ kv. Then by (5)

$$G = 700\left(\frac{0.30 - 0.17}{1.00 - 0.30}\right) \div \left(26 - \frac{0.30 - 0.17}{1.00 - 0.30}10\right) = 5.4 \text{ kv per foot}$$

or a gradient of 5,400 kv per microsecond.

Induced Voltage. When a direct stroke contacts a ground wire it imposes a negative potential on the stricken conductor and, by coupling, on all other neighboring conductors. But the potentials existing on these conductors due to the release of their bound charges by the lightning discharge are positive. This positive potential may or may not be greater on the top than on the bottom conductor, depending upon the heights of the conductors and their coupling factors. In the case of the Glenlyn-Roanoke line the positive voltage is greater on the top conductor by 30 per cent. Now let[4]

$+e$ = voltage on top conductor due to bound charge

$+e'$ = voltage on bottom conductor due to bound charge

Then the voltages across the insulators for the top and bottom conductors respectively are, as in (1) and (2)

$$V = E(1 - C) - Gx + e \quad (6)$$

$$V' = E(1 - C') - G(x + y) + e' \quad (7)$$

and the difference in the voltages is

$$V' - V = E(C - C') - Gy - (e - e') \quad (8)$$

Thus the bound charge voltages tend to neutralize the differential in coupling if, as in this case, $e > e'$.

"Stolen Flashovers." Operating experience has failed to show concrete evidence of midspan flashovers, although calculations indicate that they should occur on many lines. This has lead to the speculation that lightning wave fronts are slower than those used in calculations (one or two microseconds). However, it may be possible, and certainly appears theoretically feasible, that midspan flashovers do occur, but the 60-cycle midspan arc is robbed by a subsequent insulator flashover at the tower.[3] The mechanism of this possibility is envisaged as follows:

Suppose a lightning stroke contacts a ground wire at midspan and flashes over to the (top) line conductor. Then waves of equal voltage move toward the tower. At the tower the voltage on the ground wire is reduced to the RI drop of the footing resistance, but the surge on the stricken line conductor is not relieved. The insulator, or protector gap, then flashes over to the tower. But the insulator arc is much shorter than the midspan arc, and the latter therefore extinguishes, leaving the 60-cycle power arc across the insulator. Consequently the "evidence" exonerates the midspan; although the midspan flashover really precipitated the insulator flashover, and an insulator flashover would not necessarily have occurred if one had not taken place at midspan.

REFERENCES

1. PROTECTION OF TRANSMISSION LINES AGAINST LIGHTNING: OPERATING PRACTICE AND EXPERIENCE, W. W. Lewis. *G. E. Review*, June 1937.

2. Discussion by S. M. Zubair, ELECTRICAL ENGINEERING, March 1936.

3. FLASHOVERS ON TRANSMISSION LINES, L. V. Bewley. ELECTRICAL ENGINEERING, April 1936.

4. CRITIQUE OF GROUND WIRE THEORY, L. V. Bewley. AIEE TRANSACTIONS, volume 49, March 1931.

Philip Sporn and I. W. Gross: As pointed out by Mr. Allen, of the 11 external flashovers of tubes on the Roanoke-Fieldale line, only three appeared to be what might be called complete tube assembly flashovers, the other eight resulting from expelled gases contacting the line conductor and thus short-circuiting one tube only. This condition was not experienced prior to the installation of the grading shields on the gap end of the V-type tubes. Analysis of tube faults at the time the paper was written had not brought out this point, and we are glad that Mr. Allen has mentioned it in his discussion. It appears that this situation can be taken care of adequately by an alteration in the venting of the tube which certainly would be done in present-day new-tube application.

We believe Mr. McEachron has misinterpreted our statement at the end of the section on "Multiple Strokes," or perhaps the statement was not made entirely clear. What we intended to convey was that since the majority of lightning strokes are negative it might be expected the positive conductor would develop power flashover first regardless of whether the lightning stroke hit the conductor or ground wire. A breakdown of the data in table XII, however, does not indicate that this always is true as there are several cases where the faulted conductor is of negative polarity.

The question of coupling, of course, is distinctly in the picture, and the discussion of Messrs. McEachron and Bewley on this point is an interesting speculation of what may be expected to occur. In breaking down the data of figure 12, however, it does not appear that the faults in every condition can be justified on this basis alone.

The phenomenon of the midspan stroke has always been one which has appeared quite possible in theory but its actual occurrence has heretofore, at any rate not been substantiated by field experience as determined from physical damage to the line. Mr. Bewley's explanation of how this action would take place is most interesting. A large mass of data has been collected during recent years which, if thoroughly analyzed, might throw some further light on this subject.

Regarding Mr. Wade's analysis of the probability of tube operations over a period of time, it is interesting to note how closely his calculations check with field experience. As mentioned in our paper, we do not feel, as a result of our own experience in the field, that erosion of the tube is a factor in determining its life even considering the multiple nature of the lightning stroke.

Corona Voltages of Typical Transformer Insulations Under Oil—II

By F. J. VOGEL
ASSOCIATE AIEE

SOME 13 years ago, Doctor L. Dreyfus[1] published a paper on insulation design of transformers. In this paper, he assumed that electrical breakdown adjacent to square edges was a function of the stress and the distance over which this stress acted; in other words, that it was a function of the voltage gradient along a line of force for some indeterminate distance. By means of conformal representation, he was able to determine the field shape at the corners of structures representative of those in transformers. He could then evaluate the strength of these various structures. His paper was principally mathematical, and it is the purpose of this paper to call attention to his work, to restate some of his assumptions and the conclusions that he reached, and to furnish some experimental data.

In the discussion of the previous paper on this same subject, questions as to fundamental data on the dielectric strength of oil were raised. Data on this subject are included and it is shown that in practical transformer structures, Doctor Dreyfus' assumptions seem to be correct. The relationship is shown that the breakdown of barriers involving the use of square corners theoretically follows the two-thirds power of the barrier thickness. It is also shown that, due to Dr. Dreyfus, quantitative relationships existing between different arrangements can be found and it is thought that they furnish a powerful tool for practical insulation design.

The simplest arrangement of edges is that consisting of two edges opposite each other with various angles of opening α and β as shown in figure 1.

It was found in Doctor Dreyfus' paper, for the assumptions made, that the breakdown strength would vary according to various powers of the distance d. For example, for β equals 180 degrees and α equals 90 degrees (shown in figure 2) the strength should vary as $d^{2/3}$. If β equals 180 degrees and α equals 0 degrees, the strength should vary as $d^{1/3}$. If both equal 180 degrees, the strength was shown to vary directly as d. In addition, Doctor Dreyfus showed that for the case shown in figure 3, the breakdown strength should vary as $d^{2/3}$. The mathematical solution and method of conformal representation can be found by reference to Doctor Dreyfus' paper or a textbook.[1]

Experimental Data for Air and Oil

It is always of interest to check such mathematical calculations with experimental data to see how closely they agree, and to see whether the assumptions are sound. One such check would be to see if the dielectric strength between plane surfaces does vary directly with the distance. In the case of air, data have been published by Schumann,[2] and checks have been made by extrapolating the data for spheres and rounded surfaces in air (figures 4 and 5). These show that the dielectric strength of air between plane surfaces does not vary directly with the distance, but rather as the 0.92 power of the distance.

Cornered electrodes in air have been studied and the results for square-cornered electrodes are shown on figure 6. These results indicate that the dielectric strength for air between a square corner and plane does vary as the two-thirds power of the distance in agreement with the theory.

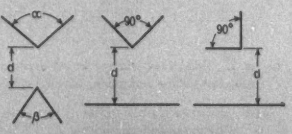
With the above data for air in mind, it is of interest to consider similar data for the dielectric strength of oil. Figure 7 shows data taken on bare rounded electrodes under oil. By extrapolating these curves, it is possible to arrive at the probable dielectric strength of oil between planes as varying as the three-fourths power of the separation, as shown on figure 8. These data were taken in oil at room temperature, and are minimum ten-minute hold values, found by five successive tests at the same voltage. To agree with the theory, the variation should be directly with the distance.

Data for conditions approaching square corners to a plane under oil have been published by Bellaschi,[3] and his results are shown in figure 9. The strength apparently varies about as the one-half power of the separation instead of as the two-thirds power.

The conclusion might now be reached that the assumptions made in Doctor Dreyfus' paper would not hold for oil alone. However, it is to be noted that transformers do not generally use oil alone, but various combinations of oil and insulating materials.

Experimental Data for Insulation Combinations in Oil

In the case of insulation barriers, much data have been previously published. For example, in the previous paper,[4] 60-cycle and impulse data for the $2^3/_8$-inch and $4^3/_8$-inch barriers were published. In these tests, the oil distance from the electrodes to the first or adjacent angle was varied for both thicknesses. It might be expected that the strength of the oil, say for a $^3/_8$-inch space between the electrode and first angle, would be



Figures 1–3. Typical arrangements of electrodes with corners

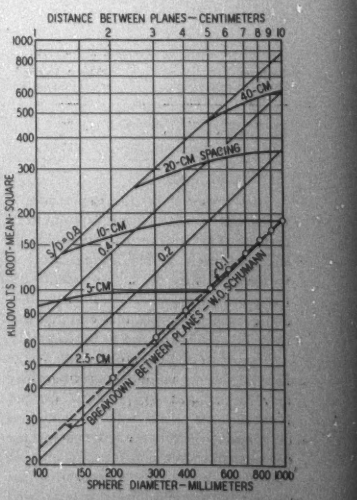


Figure 4. Breakdown voltage in air of sphere gaps with varying diameters at constant spacing

Paper number 38-52, recommended by the AIEE committee on electrical machinery, and presented at the AIEE North Eastern District meeting, Lenox, Mass., May 18–20, 1938. Manuscript submitted March 14, 1938; made available for preprinting April 19, 1938.

F. J. VOGEL is division engineer with the Westinghouse Electric and Manufacturing Company, Sharon, Pa.

1. For all numbered references, see list at end of paper.

constant regardless of the barrier thickness. If so, one of the assumptions in Doctor Dreyfus' theory would be fulfilled, and the corona strength should vary with the two-thirds power of the thickness of the whole barrier; this was found to be the case.[4] It is of interest that the corona strength of the barrier as a whole decreased with increased space between the electrode and the first angle. The following conclusions can be drawn:

1. The dielectric strength of oil depends greatly on the length of the oil space. It is greatly increased in terms of volts-per-inch by decrease in the jump distance.

2. The work of Doctor Dreyfus holds in actual transformer structures and the dielectric strength varies as the two-thirds power of the thickness when the arrangement and allocation of square corners remains the same.

Applications

Once it has been shown that Doctor Dreyfus' assumptions are valid, a very powerful method of analysis becomes possible. Experimental work on barriers can be performed to determine the effect of various arrangements of insulation adjacent to the corner. For example impulse tests were made on a $4^3/_8$-inch thick barrier under oil with seven interleaved angles, and also with only two interleaved angles. Also similar tests were made with the two angles close to the electrode. These barriers were *not* vacuum filled with oil. The impulse strengths of these arrangements were as follows:

Barrier Arrangement	Impulse Strength (Several Shots Only)
Seven angles, equally spaced	1,020
Two angles, separated	900
Two angles, close together	1,300

These tests show the importance of the insulation arrangement adjacent to the corner. The designer can determine the effect of such simple arrangements of various kinds by tests. As described in the previous paper, to obtain maximum and consistent results, it is essential that there be no air included in the assembly.

Once these data are obtained, Doctor Dreyfus has shown in his paper how they may be applied in practical designs. However, his work was mathematical only, and it is easier for a designer to use curves than to work out formulas for each individual case. Curves for some of the simpler cases applicable to practical design are shown in figure 10.

How these data and figures can be used practically for 60-cycle design can be demonstrated as follows:

Let us assume a barrier with an interleaved angle of one-eighth inch thick fullerboard not over three-eighths inch from a square edge. This approximately square edge is to be formed by a copper strap insulated with 0.120-inch thickness

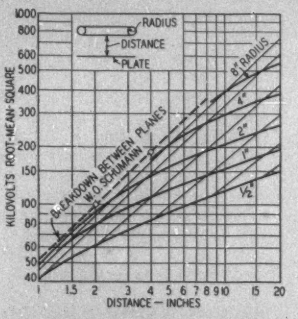


Figure 5. Corona voltage in air between rounded disks and plane, or between rounded surfaces, cylinders, etc., and plane at large separations

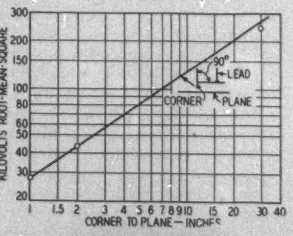


Figure 6. Breakdown voltage in air with square-cornered electrodes

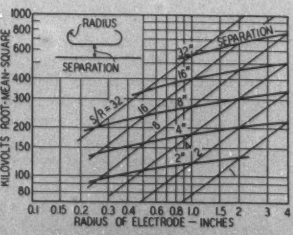


Figure 7. Breakdown voltage in oil between rounded surface and plane, 60 cycles

Heavy curves are for constant separation between surface and plane

Diagonal lines represent constant ratio between separation and radius

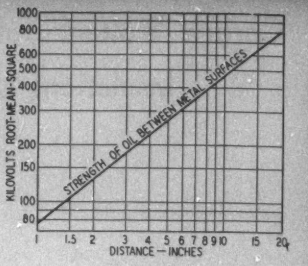


Figure 8. Breakdown voltage in oil between plane surfaces

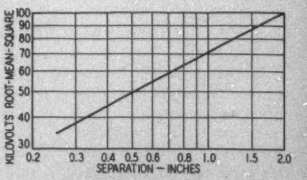


Figure 9. Breakdown voltage in oil with square-cornered electrodes

of paper. Approximate data for such barriers are shown on figure 11.

If we wish to determine safe insulation clearances, for the corner only, for a core type transformer, and for conditions where the space between windings and hence the reactance, is to be kept a minimum, we may refer to figure 10, case I. If we make H equal to about 2 m, it is seen that we can use the fundamental data from figure 11 multiplied by 0.93. It appears useless to make H, the distance to the yoke, much more than three times the space between windings. However, it may be desirable, for shell-type transformers, to keep the space between windings and to the iron the same. To meet 277-kv tests, with *no* factor of safety, a clearance of $2^7/_8$ inches for core type, or 3.6 inches for shell type transformers might be used. These values, of course, should not be used in actual design but are given for illustration of the method only.

Let us suppose that we desire to make a core-type transformer with a thin high-voltage coil as used in some types of series transformers. If the coil were to consist of a single layer, say one-half inch thick, we might apply the data from figure 10, case IV. If we assumed three inches for m, the ratio h/m would be $^1/_6$ or 0.167. From figure 10, the factor is 0.88. From figure 11, a three-inch separation would result in 315 kv

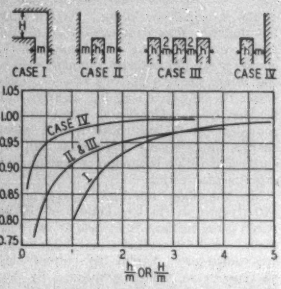


Figure 10. Effect of field form on insulation breakdown in oil of square-cornered electrodes

$V = LV_0$ for cases I, II, and IV
$V = 2LV_0$ for case III
where V_0 equals breakdown in oil between sharp corner and flat plate

strength. Multiplying by the factor 0.88 would give 277 kv strength as in the previous cases.

It is clearly seen that factors for various conditions can be determined either experimentally or mathematically. Thorough tests to determine the dielectric strength on one simple typical corner construction will then furnish very complete information for design purposes. The use of this method is not confined to 60-cycle design alone, since it can be shown that it is equally well applicable to impulse-strength calculations.

Conclusions

The work of Doctor Dreyfus and the tests reported in this paper both show that the arrangement of the insulation at the corners of transformer windings is of great importance to the designer, and that to obtain the greatest strength the area under greatest stress must obviously be free from air. If this condition is obtained, consistent test agreement with the theory for square corners can be obtained, and so-called "form factors" can be developed for design purposes. Experimental data for one reference condition can be derived which will be useful in general applications, and with "form factors" it is unnecessary to make countless other tests for every variation in design proportions.

References

1. Ueber die Anwendung der Theorie der Konformen Abbildung zur Berechnung der Durchschlags und Ueberschlagserscheinungen zwischen Kantigen Konstructionsteilen, *Archiv. Electrot.*, volume 13, 1924, page 123.

2. Electrische Durchbruchfeldstarke von Gasen (a book), W. O. Schumann. 1923.

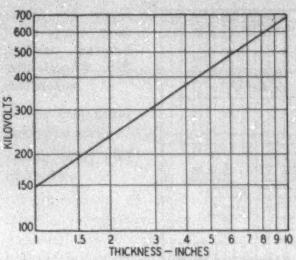


Figure 11. Breakdown and corona voltage in a typical interleaved barrier in oil with insulated electrode

3. Dielectric Strength of Transformer Insulation, P. L. Bellaschi and W. L. Teague. AIEE Transactions, 1937, page 164.

4. Corona Voltages of Typical Transformer Insulations Under Oil, F. J. Vogel. Electrical Engineering, January 1938, page 34.

5. Theory of Functions as Applied to Engineering Problems (a book), R. Rothe, F. Ollendorff, and K. Pohlhausen. Technology Press, 1933.

Discussion

V. M. Montsinger (General Electric Company, Pittsfield, Mass.): Mr. Vogel has presented some valuable fundamental data on the laws of the breakdown voltage versus spacing of air and oil. I shall confine my remarks to the dielectric characteristics of oil, as air is seldom used as an insulating medium in power transformers other than around the outside porcelain of the bushings.

My experience and data have borne out quite well the laws derived by Dreyfus, namely, that for nonuniform fields the breakdown voltage of oil varies approximately as the spacing raised to the $^3/_4$ power, and for uniform fields the breakdown voltage varies approximately as the first power of the distance. My work was independent of Dreyfus' work.

Figure 1 of this discussion shows that with 12-inch vertical disks having one-inch radius on the edges, the breakdown voltage of oil varies as the 0.92 power of the distance. These electrodes produced a fairly uniform field. I am at a loss to know why Mr. Vogel's values shown in his figure 8, giving breakdown in oil between plane surfaces, are so much lower than my values. I note that Mr. Vogel's breakdown voltage varies as the 0.77 power of the distance which does not agree either with Dreyfus' prediction, or with my data (0.92 power).

Figure 1 also shows to what extent the breakdown varies for a given distance with and without pressboard in series with the oil. For example, the highest breakdown is obtained with a thin sheet of pressboard adjacent to each electrode in a vertical position. The lowest breakdown occurs with these electrodes (bare) in a horizontal position. The insertion of $^1/_{16}$-inch pressboard either half-way between the electrodes, or against one electrode only, has very little effect on the breakdown as obtained with oil alone in the gap.

Figure 2 of this discussion shows the effect of the position of the two ten-inch electrodes on the breakdown of oil. These curves show that when the electrodes were horizontal, the breakdown varied as the $^3/_4$ power of the distance. With the electrodes

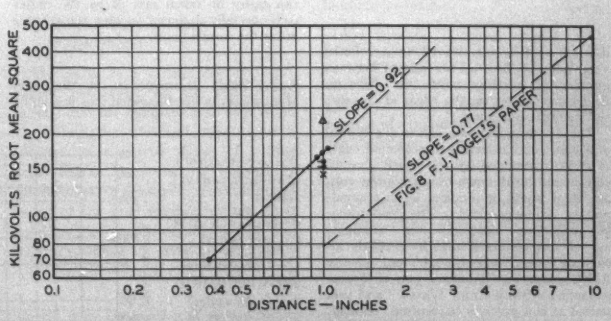


Figure 1. One-minute 60-cycle tests; breakdown voltage of oil between 12-inch disks in vertical position (unless otherwise specified)

Temperature 25 degrees centigrade
One-inch radius—oil strength varied from 28 to 33 kv
(One-inch disks, 0.1-inch gap)

		Spacing (Inches)	Number of Tests Made
△	$^1/_{32}$-inch pressboard + $^{15}/_{16}$ inch oil + $^1/_{32}$-inch pressboard	1	3
o	Oil	$^3/_4$ and 1	14 and 25
o-	$^{15}/_{32}$ inch oil + $^1/_{16}$-inch pressboard + $^{15}/_{32}$ inch oil	1	1
-o	$^1/_{16}$-inch pressboard + $^{15}/_{16}$ inch oil	1	2
x	Oil (electrodes horizontal)	1	12

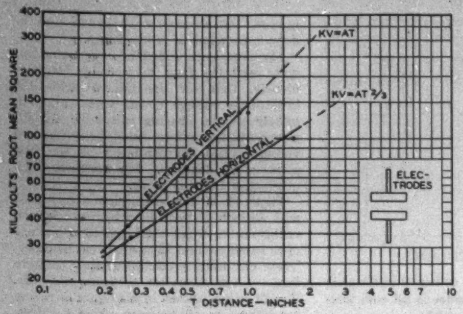


Figure 2. Breakdown voltage of oil between ten-inch disks, 60-cycle one-minute tests

Temperature 25 degrees centigrade

Each point average of five tests

vertical, the breakdown varied directly with the distance. The difference was due, no doubt, to the fact that impurities and gaseous bubbles have a better chance to bridge the gap between horizontal electrodes than between vertical electrodes. Other tests, I believe, have shown that with deaerated pure oil there is no difference in the breakdown between vertical and horizontal electrodes. This is a factor which was not taken into consideration by Dreyfus' work, and it shows that breakdown will not always follow predictions under all conditions.

Figure 3 of this discussion shows the effect of the shape of the electrodes on the breakdown voltage of oil. Briefly these curves show that:

1. The highest breakdown is obtained with large vertical disks having well rounded edges.
2. The lowest breakdown is obtained with a needle point and a plane.
3. With the exception of the upper curve *A*, the breakdown varies very closely with the spacing raised to the $^3/_2$ power (slope of lines = $^3/_2$ on log log paper).

Mr. Vogel's figure 11, showing breakdown of a typical interleaved barrier, checks very well my data on breakdown between interleaved windings where the dielectric field concentrates on the edges of the outside coils of each group.

These low breakdown values are typical of a construction having unprotected edges of coils surrounded by oil, which give off corona and break down at much lower voltage than would be required in an approximately uniform field. The importance of protecting electrodes (or windings) against low corona voltage by properly insulating them, was brought out in my AIEE paper on "Co-ordination of Transformers for Steep Front Waves," and presented at last winter's convention. Briefly, with a square edge line end electrode, corona occurred as low as 60 to 65 per cent of the single impulse voltage application strength, while with a proper design of the line end electrode the breakdown point was not only increased but corona did not occur until approximately 80 per cent of the single-shot kilovolt strength was reached.

With ideal electrodes, distances far below those shown in figure 11 are possible. For example, a 138-kv oil-filled cable uses only approximately $^5/_{16}$ inch of paper between the cable and lead sheath. In contrast with this, figure 11 of Mr. Vogel's paper shows that in an interleaved design a distance of 2.5 inches will fail at 277 kv which is the test voltage of a 138 kv transformer. In other words, the distance used must be (for a reasonable factor of safety) from six to eight or ten times that used in oil-filled cables. While the minimum distance as used in cables can probably never be obtained in transformers, on account of less ideal electrodes, it is possible with concentric windings to come nearer to the ideal flux distribution than the arrangement shown in figure 11.

From the standpoint of obtaining uniform dielectric fields between windings, the concentric type of winding offers many advantages to the designer, especially in cases where the line connection is brought out from the middle of the stack and the ends of the stack are grounded. There are no sharp corners to be protected and the dielectric field between windings is quite uniform.

With this type of winding even when the line coils are on the ends of the stack, there are never more than four corners where the dielectric field must be improved and these can easily be taken care of by the buffer coils specially designed to keep the stresses below the corona point.

F. J. Vogel: It seems to me that Mr. Montsinger, in his discussion, has lost sight of the principal conclusion. That is, that for similarly shaped square-cornered electrodes, in combination with insulation, the corona point and dielectric strength vary as the dimensions to the $^2/_3$ power. Even where the edges are rounded slightly, similar laws hold. The use of "form factors" provides the designer with a tool which enables him to vary proportions with security and with a minimum of fundamental experimental testing.

Mr. Montsinger has drawn his conclusions with regard to the breakdown of oil between plane surfaces from data at two relatively small separations, and by average breakdown tests. I think the reason for the discrepancy in values mentioned by Mr. Montsinger is due to the method of test. The tests reported in my paper were the minimum of five ten-minute hold tests instead of average breakdown tests. This explains both the difference in values and in the variation of dielectric strength with distance. It is of interest that for small separations, the breakdown voltage is not greatly affected by the use and location of fullerboard barriers. This is not the case with larger separations or if corona voltage instead of breakdown voltage is taken into consideration.

Figure 3 combines on one sheet data on many different arrangements. They are of interest in not being consistent. Oil, not deaerated, nor carefully processed, varies greatly in dielectric strength. Curve *B* exceeds curve *A* at small separations. They should merge together if the breakdown voltage between planes varies directly as the distance. Either the values from *B* for small separations are too high, or the values from *A* for small separations are too low. The dielectric strength of oil between planes does not vary directly as the distance between them if the latter is true.

Curve *E*, figure 3, is for an electrode condition similar to figure 9 of my paper, and it is noted that Mr. Montsinger's data are lower than mine for small separations and approximately the same for two-inch separation.

In the application of these data to design, it has been found that the corona value

A—Twelve-inch disk (one-inch radius) vertical

B—Four-inch disk ($^1/_8$-inch radius)

C—One and three-eighths inch diameter rods (right angles)

D—Four-inch disk (square edges)

E—Square-edge flange and plane

F—Two needle points

G—Needle and plane

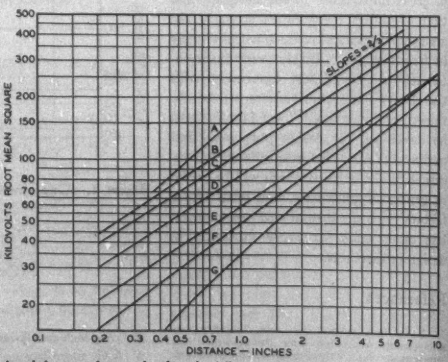


Figure 3. Sixty-cycle breakdown voltage of oil with different electrodes, one-minute tests

Twenty to 25 degrees centigrade

Oil strength ranged from 25 to 30 kv (one-inch electrodes, 0.1-inch gap)

Systematic Voltage Surveys—Procedure and Application to Distribution Design

By R. W. BURRELL
ASSOCIATE AIEE

W. E. APPLETON
ASSOCIATE AIEE

WITH the development of systems of distribution supplying light, heat, and power from common mains, the problem of maintaining proper voltage at consumers' services has become extremely difficult. The efforts of distribution engineers in solving system voltage regulation problems have extended in many directions. To facilitate these solutions, a need has been felt by many distribution engineers for some means of clarifying the approach to the voltage-regulation problem. The systematic voltage survey, by presenting a comprehensive view of service voltage conditions, has been found, by utilities which make such surveys periodically, to serve this purpose effectively. This paper presents a procedure for conducting systematic voltage surveys, based on the practice of various electric utilities, and a brief discussion of the application of voltage-survey data.

Distribution systems are not static, but are in a continual process of development. In the course of rearrangements occasioned by load growth, some primary and secondary mains become too long, or overloaded, or distribution transformers become overloaded, with resultant adverse effect on regulation standards. To maintain voltage within system regulation standards under these conditions, the distribution engineer must have some method of ascertaining the status of service voltage conditions over the entire system. Because of the variable factors involved, it is impractical, if not impossible, to calculate with any degree of accuracy the value of voltage at consumers' services, involving as this may, approximations of load on primary laterals, distribution transformers, secondaries, and services. The systematic voltage survey is an effective means of obtaining this information, and has proved to be a material aid to the distribution engineer in providing good voltage service.

The procedure involved in making a voltage survey necessarily varies among different utility systems in accordance with individual system requirements. Data received from various companies regarding voltage survey practice indicate, however, that there is considerable uniformity in the consideration of certain fundamental aspects.

In considering plans for making a voltage survey for the first time, engineers are concerned with certain phases which may be divided into the following categories, namely,

(*a*) Preliminary engineering considerations.
(*b*) Preparation of data for field test forces.
(*c*) Procedure for field testers.
(*d*) Recording of tests, classification and tabulation of results.
(*e*) Analysis and application of data.

Preliminary Engineering Considerations

The value of a voltage survey is primarily dependent on the relative accuracy and the completeness with which the information obtained presents an indication of the true status of voltage conditions on the system. To insure the effectiveness of the survey from the standpoint of the final engineering use to be made of the data obtained, careful consideration must be given to the type of readings desired, location and number of readings to be taken, time of taking readings, etc.

Types of Readings

There are two basically different types of voltage surveys—those taken by means of graphic instruments, and those taken by means of indicating instruments. Although the cost of a voltage survey is on the whole increased by the use of graphic instruments, the added cost is offset by the fact that a complete record of voltage variations and fluctuations over a 24-hour period is available, which in many cases adds greatly to the understanding of the regulation problem. On the other hand, the use of indicating instruments speeds up a voltage survey and allows the use of a less highly trained personnel. The element of completeness is taken care of by increasing the number of readings taken. In this connection it may develop that a large number of indicating readings thoroughly covering an area will prove of greater value than a limited number of graphic records taken at a few points only, as the few graphic records may fail to disclose the extent of the poor voltage conditions. As a rule, a large number of indicating readings taken in an area should not fail to disclose low spots and high spots; and where conditions are suspicious, they may be supplemented by the more thorough graphic charts. This is usually the practice of companies which standardize on indicating readings.

The use of graphic instruments permits a check on the average voltage supplied to a consumer, which is important as it is desirable that the average voltage supplied by a system shall match the rated voltage of equipment for best service to the consumer. Nevertheless, most systems have set up *limits* of voltage service and their experience has been that if the greater part of the service voltages are kept within these limits, as indicated by spot readings, the average voltage supplied to the services will not deviate greatly from the system nominal voltage.

Location and Number of Readings

In arranging the details of survey procedure, a most important point to be de-

and breakdown value can be made practically equal. At any rate, the ratio between corona voltages, impulse and 60 cycle, can be made the same as the ratio between breakdown voltages, impulse and 60 cycle. It is easily seen that if there is a definite ratio, that voltage values for impulse tests can be established from the present 60-cycle test values and should be consistent. The value of 80 per cent as applied to the ratio between corona and single-shot kilovolt strength is not representative of "proper design."

The comparison of concentric types of winding with interleaved types is unfortunate, since the number of square corners is just the same (four) on the usual core type as in the shell-type winding with two high-voltage groups. However, no merit is seen in the number or lack of number of such corners since one or 20 can be insulated in the same way. Theoretically, some reduction in space between high-voltage and low-voltage windings can be made where the high-voltage lead is brought out at the center of the coil stack, but the outside shield and its insulation required to obtain a satisfactory voltage distribution also takes space and offers difficulties avoided by other types of design.

Paper number 38-48, recommended by the AIEE committee on power transmission and distribution, and presented at the AIEE North Eastern District meeting, Lenox, Mass., May 18-20, 1938. Manuscript submitted February 19, 1938; made available for preprinting April 26, 1938.

R. W. Burrell is assistant engineer, Consolidated Edison Company of New York, Inc.; W. E. Appleton is division engineer, New York and Queens Electric Light and Power Company, Flushing, N. Y.

cided is the location at which readings should be taken. The voltage which influences the operation of equipment is that which is directly supplied to the terminals of the equipment; however, it is not practical, for example, to measure the voltage at the lamp sockets. The next best point, therefore, is considered to be at the consumer's service switch.

Practical considerations preclude taking voltage readings at all services. The number of readings taken should be sufficient, however, to represent a fair sampling in order that the results may be indicative of the conditions existing. To facilitate subsequent corrective measures, readings should be taken at a sufficient number of service points to disclose whether subnormal voltages are caused by primary circuits, secondary mains, or services. On radial systems readings should be taken at the consumer nearest each transformer and at a consumer at the end of at least the longest secondary branch. Where a secondary has several branches of unequal loading or a complicated configuration, judgment may dictate that more than one branch reading be taken. Special conditions may warrant taking additional readings at various points along the secondary.

A careful analysis of secondary layouts, in establishing a voltage-survey procedure, will do much to eliminate unnecessary readings. Where considerable growth is taking place on a secondary system, a certain amount of secondary rearrangement is made from year to year and successive voltage surveys must be made to conform. On the other hand, it has been found good policy in making successive surveys to choose locations in a consistent manner, and where no rearrangement has been made, to choose approximately the same locations as before in order that yearly comparisons of results may be more closely indicative of actual change.

On network systems many of the same points hold. As network secondary grids are fairly uniform in arrangement, a reading at the first consumer off the transformer and at one or two intermediate points between transformers generally suffices. Where the network grid is incomplete, additional readings on long spurs may be desirable.

Number of Readings at Individual Locations

The decision must be made as to whether or not all possible line-to-neutral readings should be taken at each location. Practice naturally differs, but with indicating instruments, particularly, the additional time and expense involved in taking more than a single line-to-neutral voltage would appear to be justified by the information obtained regarding voltage unbalance. For this reason, where a choice of consumer locations is available, three-wire services are to be preferred to two-wire services. In the case of three-phase secondaries the readings should be taken, wherever possible, on a three-phase service. It may be desirable to read the line-to-line voltages as well as the line-to-neutral values—the former for reference and check purposes, the latter for comparative records.

Time at Which Readings Are Taken

In a district which is predominantly residential, the peak load will usually occur at some hour during the evening in the winter. If a district is on the average an industrial district, the peak load will usually occur at some hour during the day and may be either in the summer or in the winter. There may be some residential load in an industrial district and some industrial or commercial load in a residential district, but if these loads make up only a small portion of the entire area, the expense of surveying them separately may not be justifiable. In general, the readings should be taken at the time the peak load is occurring in the district.

The time of the year and the extent of time over which the survey will be conducted will be determined ordinarily by the load characteristics of the system and the personnel available for carrying on the field work. Common practice is to schedule the ordinary lighting-load survey over the winter months and the survey on industrial loads and summer resorts over the summer period. This allows a year-round distribution of work on the field test forces. It has been found convenient by some systems to schedule daytime industrial-load readings as well as night lighting-load readings over the "winter peak" period to fit in better with the routine work of the field forces and relieve special personnel requirements.

Where seasonal variation of load over the "winter peak" period is limited, it may be feasible to schedule the voltage survey for any time during the period from October to April. If the load variation is considerable, it still may be desirable to take readings over a long period and correct voltage readings for variation of system demand. Such voltage readings can be corrected to allow for the difference between the feeder load at the time the readings were taken and at the time of feeder peak.

Generally speaking, readings in residental areas will be taken on week-day nights from 6:00 to 10:00 p.m. It may be desirable to take readings in store-load districts on Saturday nights. In industrial districts readings may be taken between 9:00 a.m. and 4:30 p.m. with allowance for the noon-day load dip. Where there is any doubt, an analysis of feeder load characteristics will indicate the desirable time for a particular area. Corrections for "off time" readings are not generally made, unless they are found on the "border line."

Preparation of Data for Field Test Forces

With the question of type of data decided, thought must next be given to the procedure for obtaining the data.

Prior to the beginning of field operations a certain amount of engineering study will generally be found necessary. The territory should be divided into the districts by which it is desired to keep records. Whether the territory consists of a closely built up urban area or an extended system with natural divisions, it will usually be found advantageous to proceed with the survey in terms of such districts as best fit the system, such as by towns, substation districts, or arbitrary divisions used in connection with existing operating records. For convenience it may prove advantageous to subdivide the major divisions to correspond to the grouping of secondary circuit maps. Tabulation of the readings by districts, adopted on this basis, will facilitate the analysis of voltage conditions and help in the consideration of plans for system reinforcements. Further tabulations can be made according to types of load, for example, residential-commercial and industrial readings.

Some form of indication must be devised to indicate to the field forces where and when readings are to be taken. This can be done by using secondary maps as the direct medium of designating the locations at which readings are to be taken, as illustrated in figure 1. These secondary plates are designated by plate numbers to which the survey records are indexed.

A procedure for using these plates in connection with indicating readings is as follows: A volume, consisting perhaps of approximately 100 blueprint plates covering a district, can be inspected by one or more engineers familiar with the secondary system to determine the lo-

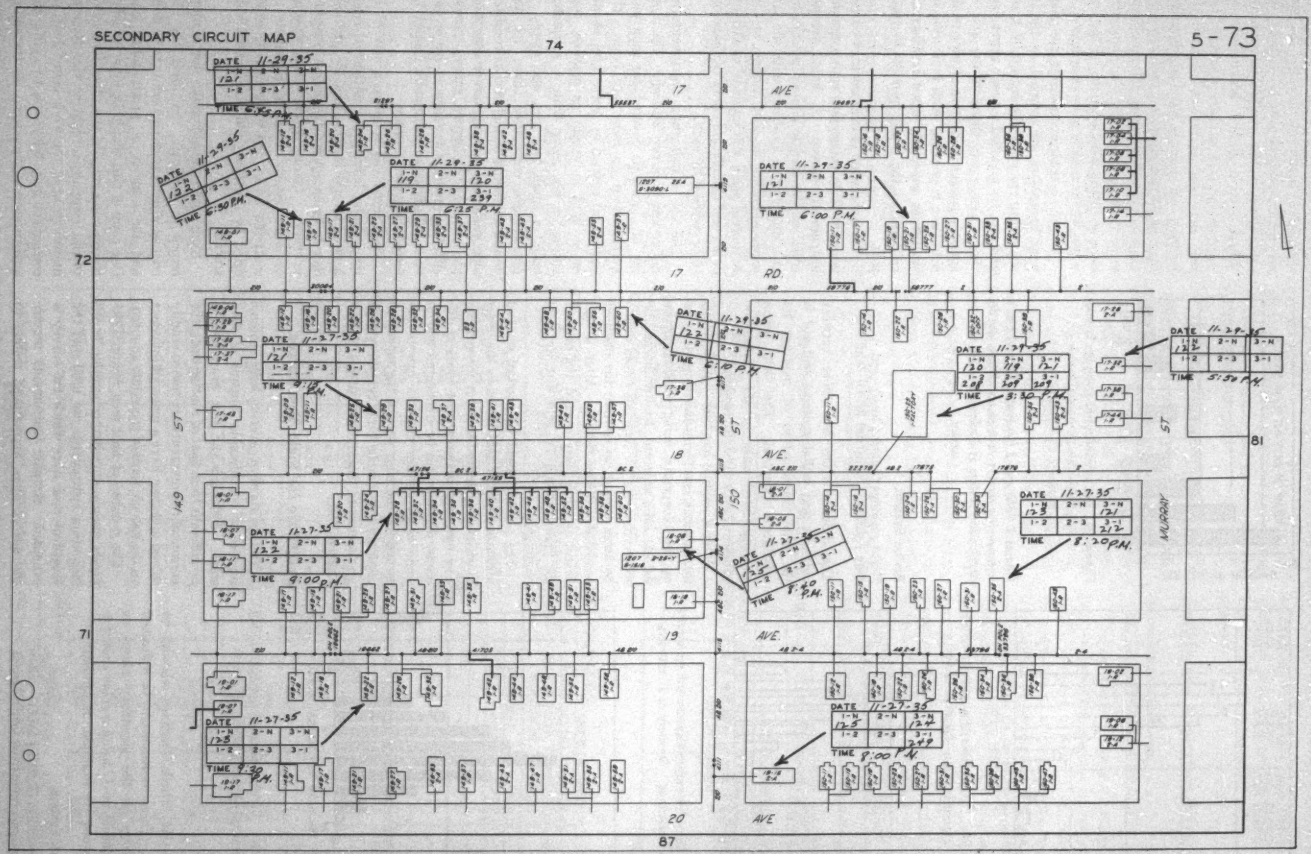


Figure 1. Secondary-circuit maps adapted for voltage-survey use. Test locations shown and indicating readings recorded directly on secondary blueprints

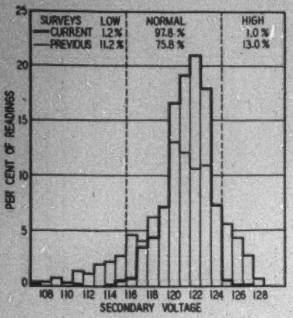


Figure 2a. A-c radial-system voltage survey, Verona district. Night readings

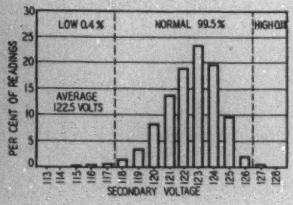


Figure 2b. A-c network-system voltage survey Night readings. Summary of all districts

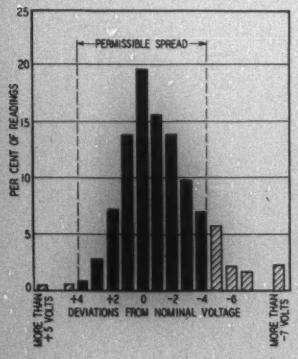


Figure 2c. Service entrance voltages during principal lighting hours, district A

cations at which readings should be taken. These locations can be indicated by arrows on the secondary plates as shown in figure 1, using a color code for the arrows, for example, as follows:

Network System

Night readings (lighting load)—yellow
Day readings (industrial load)—green

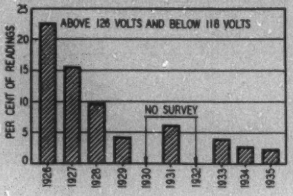


Figure 3. A-c radial-system voltage survey Readings outside normal range Summary of all districts

Figures 2 (left) and 3 (above). Typical charts summarizing service voltage conditions on the distribution system as disclosed by the voltage survey

Radial System

Night readings (lighting load)—red
Day readings (industrial load)—white

The differentiation by colors between network and radial systems will aid in the final classification of readings for tabulation purposes. The field forces are interested only in the distinction between day and night readings.

After a volume has been "marked up" for locations, box forms should be stamped on the blueprints, using contrasting indelible ink, adjacent to the arrows, as shown in figure 1. The box forms should be large enough to contain the readings recorded by the testers. After a sufficient area has been covered, the marked up plates should be sent out for field readings.

The plates should be marked up and forwarded to the field forces in the order in which it is desired to cover the system. The variation between peak loads in different districts can be considered and in some cases certain districts can be reserved for the later part of the survey to allow for the completion of certain system arrangements, substation cut-ins, feeder changes, etc.

Procedure for Field Test Forces

Voltage surveys covering large systems involve a considerable amount of field work. Although the test procedure is no different from that of routine tests, the personnel requirements are not so readily solved and may have a material influence on the specific form of procedure adopted.

The number of field men required depends mainly on whether graphic or indicating instruments are used and the length of time over which the survey is extended. Graphic instruments require the use of more experienced testers to set up the instruments, see that the pens are inking properly, and to check the calibration of the graphic instruments. Where several graphic instruments are to be set up at a location, a crew of two men may not average more than one location per hour. Although locations may be farther apart on radial systems than on network systems, the time factor is partially balanced by the preponderance of three-phase locations on the network, which require more instruments.

In using graphic instruments, the peak-hour limitations are avoided, as the instruments are generally set for 24 hours and can be installed at any convenient time. Test crews therefore are able to spend a greater proportion of time in the field than is possible with indicating instruments, especially when readings are confined to the hours of 6:00 to 10:00 p.m.

Transportation of instruments by truck is desirable in connection with a graphic instrument survey. A light delivery truck can be used to deliver instruments at a dozen or so locations, with the field crews following by foot, trolley, or bus. A routing sheet will indicate to delivery crews and installation crews the locations to be covered by each.

The use of indicating instruments requires less time per location. The number of locations covered per man may average four or more per hour. The equipment carried by these men should be as light in weight as possible, consisting of not more than a voltmeter, leads, a small tool bag, and maps. A temperature correction curve for the voltmeter should be included as considerable variation in temperature may take place during an entire survey period, affecting readings as much as one or two volts. Indicating voltmeters should be tested daily for accuracy.

Each tester can be given a new set of maps daily, leaving the unfinished readings of several testers from the previous day to be completed by testers traveling in trucks. During severe winter weather or when taking readings in remote or scattered areas, the work can be expedited by operating multiman crews from trucks.

Each tester should make out a route record in duplicate, indicating the district in which the days work is to be done and the number of prints taken out. One copy of this should be kept for office record purposes and the other forwarded to the company's night service force to inform them of the work being done, as consumers may telephone to verify the authenticity of the tester. At the end of

the day the tester should check off on the office record copy the number of plates covered, the number of readings taken on each plate, total number of readings taken, and any irregularities, however slight.

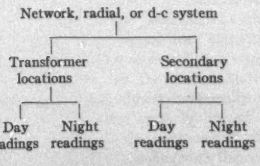
The readings recorded on the prints should be rechecked by a clerical force to see if the readings appear normal. Unusual readings should be called to the attention of the engineer in charge of the voltage survey so that an investigation of conditions can be made without delay.

Where the scale of the secondary circuit maps is such that readings cannot be entered directly thereon, this procedure can be modified to specify addresses and to record test readings on standard test forms.

Recording of Tests, Classification and Tabulation of Results

Tabulation of Readings

The readings obtained by the field forces, whether indicating or graphic, will usually be referred to distribution engineers for analysis. The data must be tabulated before they can be classified. In the case of graphic voltage charts, it is desirable to record the low and high readings for each location together with the average voltage. It is desirable that transformer readings and end-of-secondary readings be tabulated separately so that the results may be weighted according to the number of readings of each type. A number of different classifications, for each district, may be necessary, as follows:



Plotting Readings on Maps

A useful summarized record of the results of a voltage survey may be obtained by plotting the readings on a map of the territory, drawn to some small scale. Where locations are too close together to permit plotting each reading, the average may be shown, particularly if the variation is not great. Such a map is of interest to executives and to the distribution engineers in obtaining a general view of system voltage conditions. Voltage-regulation conditions on individual feeders are advantageously revealed by plotting on detailed maps of each feeder the first consumer readings of each transformer on the feeder. These maps assist the distribution engineers in studying regulation on individual feeders and on the system as a whole.

Voltage Survey Reports

The results of a systematic voltage survey may be presented in some form of periodic report. Various graphic methods are illustrated by the charts shown in figures 2*a*, 2*b*, and 2*c*. It may be desirable to contrast the results with those of the previous survey, as illustrated in figure 2*a*, to indicate improvement of system conditions. A separate chart for each district and for each type of load is usually desirable. It is also interesting to show the percentage of readings lying outside the accepted service standards as in figure 3. A tabular form of periodic report is shown in figure 4. The readings tabulated in figure 4 are the highest and lowest values as recorded on graphic charts.

Analysis and Application of Data

Engineering Analysis of Voltage Survey Readings

Whether the readings of a voltage survey are indicated directly on secondary plates, as shown in figure 1, are recorded on test forms, or are available on graphic charts filed by feeders or districts, the results should be analyzed thoroughly by the engineers in charge of the distribution system. It may be desirable to investigate further by means of graphic voltmeter doubtful high- or low-voltage conditions disclosed by indicating readings. This procedure can be extended to high and low readings one volt within the accepted service limits. All conditions

Figure 4. Monthly comparative report of voltage-survey results

MONTHLY REPORT - A.C. LIGHTING VOLTAGE SURVEY

MONTH - APRIL 1936

PERIOD	CHARTS OBTAINED	SECONDARIES SURVEYED	% OF TIME ELAPSED	% OF SECONDARIES SURVEYED
THIS MONTH				
TOTAL SINCE BEGINNING SURVEY SEPT. 10, 1934				

ESTIMATED TOTAL SECONDARIES TO BE SURVEYED

CLASSIFICATION OF VOLTAGES

% OF TOTAL LOWEST SUSTAINED SECONDARY END VOLTAGE RECORDS			% OF TOTAL HIGHEST SUSTAINED TRANSFORMER VOLTAGE RECORDS	
VOLTAGE	PRESENT SURVEY TO DATE	PAST SURVEY	PRESENT SURVEY TO DATE	PAST SURVEY
BELOW 105	.01	.03	–	–
AT 105	.01	.03	–	–
" 106	.01	.04	–	–
" 107	.05	.09	–	–
" 108	.11	.24	–	–
" 109	.32	.50	–	–
" 110	1.13	1.71	–	–
" 111	2.83	3.64	–	–
" 112	6.87	7.74	–	–
" 113	13.20	14.20	.01	.01
" 114	21.15	20.80	.09	.03
" 115	28.50	26.30	1.06	1.00
" 116	19.00	18.85	7.36	7.50
" 117	7.30	6.38	28.70	28.00
" 118	1.50	1.28	39.50	38.50
" 119	.18	.18	21.70	20.58
" 120	.03	.01	3.12	3.88
" 121	–	–	.38	.40
" 122	–	–	.06	.08
ABOVE 122	–	–	.02	.05
BELOW 112	4.47	6.28	–	–
ABOVE 119	.03	.01	3.58	4.39
AVERAGE LOWEST SUSTAINED SECONDARY END VOLTAGE			114.31 PRESENT SURVEY	114.32 PAST SURVEY

REMARKS: 4.54% OF THE SECONDARY END VOLTAGE RECORDS FOR THIS MONTH WERE BELOW 112 VOLTS.

finally determined to be above or below the accepted standards should be studied carefully to determine whether the subnormal condition is due to primary circuits, secondary mains, or service wires.

System Reinforcements Based on Survey Results

A voltage survey will disclose cases of low voltage due merely to inadequate service wires. These facilities may have been installed in accordance with old standards, inadequate for present-day loads. Such conditions are easily corrected.

Cases of unbalanced voltage will be revealed if all line-to-neutral readings are taken at each location. Some of these conditions can be corrected with little trouble by rebalancing secondary load.

Experience indicates that a high percentage of poor voltage conditions is due to the secondary mains. These conditions are indicated by analysis of the voltage survey data and may be remedied by replacing existing secondary with larger wire, by hanging additional transformers to cut down the length of secondary feed, or in some cases merely by rearrangement of existing secondaries.

In some cases low-voltage conditions can be improved by raising feeder substation voltage, provided this does not lead to overvoltage conditions elsewhere. In other cases high voltage may require lowering substation voltage.

Low-voltage conditions may be found to be due to inadequate primary circuits. Where this occurs, redesign of primary circuits may be necessary. Additional voltage readings and load readings at various points on the circuit may be necessary in such cases to provide engineers with full information. The results of the voltage survey may justify the introduction of new feeders or new substation capacity.

Where general low-voltage conditions exist over an area of relatively high load density, engineering and economic considerations may warrant changeover to underground network supply. The extension of underground network on a step-by-step basis in urban territories where all distribution is planned ultimately to be underground, is facilitated by periodic voltage surveys to disclose which areas first exceed the regulation limits of existing overhead facilities.

Conclusion

The readings of the systematic voltage survey, appropriately taken and carefully analyzed, provide the engineering justification for redesign of the distribution system to correct existing unsatisfactory voltage conditions. The periodic survey data, by revealing trends of regulation, make it possible, in planning system changes, to anticipate unsatisfactory conditions before service voltages actually fall outside the accepted standards of good service. The broad view obtained of system voltage conditions facilitates the consideration of various plans proposed, and is a helpful guide in considering the necessity for general system reinforcement and improvement projects.

It is not anticipated that a survey such as outlined in this paper need be made every year. As voltage conditions are improved, it may be found that a complete survey made every other year, or a policy of surveying a half or a third of the system each year may suffice.

Voltage Regulation and Control in the Development of a Rural Distribution System

By G. H. LANDIS
MEMBER AIEE

Synopsis: The rapid growth of rural electrification and the importance of maximum service continuity commensurate with economical expenditures has given impetus to the study of means to provide a satisfactory solution. The development of a rural network system with its sources of feed to supply this system is described. Selection of voltage rating for rural lines is often dependent upon operating conditions peculiar to the area served, and must be considered integrally with voltage regulation. Methods applicable for voltage regulation and control are reviewed with particular reference as to their application for rural line use. The economic application of regulating devices for voltage control of a rural load area is illustrated by a specific example and comparison with other means available. Methods used for obtaining a constant check of voltage conditions throughout a rural area are described and the results obtained by these means are given in a special case.

The Rural Problem

THE rapid growth of rural electrification in the past few years has stimulated activity in new methods and approach to the problem of providing adequate capacity for the present and future demands which will be made for this service. Of necessity, due to the low customer concentration, the distribution lines serving the rural areas must be constructed at a minimum cost commensurate with existing or near future usage of such service. In the United States, this has resulted almost universally in the supply of these areas by means of single-phase lines, the construction and voltage of the lines varying with the conditions encountered in the areas served, and varying with the economic, engineering, and operating conceptions of the individual utilities.

The rural area in which the Central Hudson Gas and Electric Corporation operates is probably typical of a major portion of the northern Middle Atlantic and southern New England States. The area cannot be considered strictly as a farm area. Essentially, the rural territory is a region populated by two general classes of people; first, the farmers who primarily specialize in the production of special perishable products for consumption of the large urban centers; second, small commercial and industrial enterprises in the rural centers, combined with those who have sought freedom from the city confines by temporary or permanent residence in the rural area. In the first classification, the following types of farming will dominate with their special applications of electric load:

Poultry, requiring electric service for incubators, brooders, water heating.

Stock and dairy, with milk coolers, pasteurizers, water heating, ventilating, milking machines, pumping, and general utility.

Truck and fruit, with soil heating, minor irrigation, fruit grading, insect control, spraying, pumping, cold storage.

General, with pumping, general utility.

In addition to these, the domestic usages of cooking, refrigeration, water heating, and pumping must be provided.

In the second classification, the following groups of people must be served:

Hamlets, with the country store, garage, and occasional small industrial load.

Small residential customers migrating from local urban centers.

Large residences and estates, generally drawn from the large cities.

Vacation residences, road houses and stands, boarding houses, and hotels, most of which are summer loads, but a small increasing amount is becoming either winter and summer loads, or year-round loads.

Religious, educational, and governmental institutions.

The first classification of customers requires an adequate and dependable service supply, for, in essence, they are small industrial establishments, and their livelihood is dependent upon uninterrupted service. As an illustration of the importance of continuous service, one poultry farm sells fancy stock eggs at prices as high as 40 cents each, ships quantities of these abroad for hatching, and incubates as many as 50,000 eggs at one time. An hour's interruption of the rural service to this customer may destroy a large percentage of his incubator supply.

The second classification of customers, being in a large measure people from urban territories, demand essentially the same grade of service here as that to which they have been accustomed, especially since electric service becomes more essential to their comfort and living than before.

The necessity of a high degree of continuity combined with adequate voltage control is therefore essential to the rural population. For this type of service, freedom from interruptions must be considered along with voltage control, and the choice of voltage level is in great part predicated on the ability to maintain service with the greatest freedom from interruptions.

The Rural System of the Central Hudson Gas and Electric Corporation

The franchise area supplied by the Central Hudson Gas and Electric Corporation is shown in figure 1, roughly extending 75 miles north and south along the Hudson River between New York and Albany, and 55 miles east and west, a small portion to the east bordering the state of Connecticut. The territory covers approximately 2,600 square miles and has over a quarter of a million inhabitants. The three largest cities, Poughkeepsie, Newburgh, and Kingston along the Hudson River, account for a total population of less than 100,000. Numerous villages are located throughout the area. Scenically magnificent in the mountainous regions of the Catskills and Shawangunk Mountain Ranges, beautiful for its well-kept farms and orchards, and within close driving distance of the great metropolitan areas, it attracts many thousands of vacationists.

The general layout of the Central Hudson electrical system is shown in figure 1. The company, having developed only a small amount of generating capacity (25,000 kw in water power, and 12,000 kw in steam) is dependent upon the supply of power over strategically located transmission interconnections. A well-located transmission system at 66 kv ties its main load areas into an integrated system, supplemented by secondary transmission feeders and tie lines

Paper number 38-47, recommended by the AIEE committee on power transmission and distribution and presented at the AIEE North Eastern District meeting, Lenox, Mass., May 18–20, 1938. Manuscript submitted March 18, 1938; made available for preprinting April 25, 1938.

G. H. LANDIS is electrical engineer for the Central Hudson Gas and Electric Corporation, Poughkeepsie, N. Y.

1. For all numbered references, see list at end of paper.

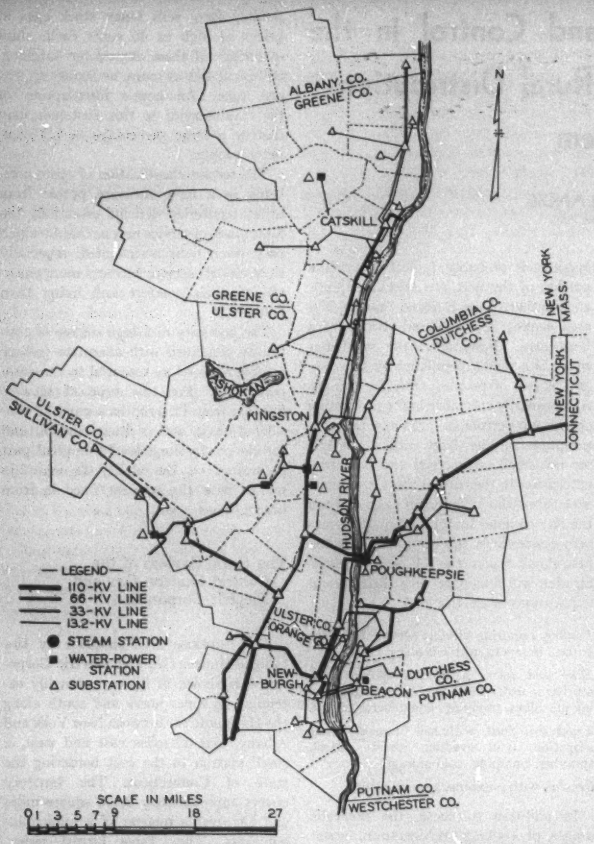


Figure 1. Franchise area showing transmission lines, steam and water-power stations, and substations

at 33 and 13.8 kv, thereby forming a fairly well-defined grid over the entire area.

Among the pioneers in recognizing the necessity, desirability, and value of rural electrification, the company initiated its rural-line program in 1924 and has maintained an aggressive and liberal policy for the development of rural loads. An accelerated program during the last two years has brought about virtual saturation of the area with rural distribution lines, these lines now being within reach of 98 per cent of the rural population. A total of over 2,700 miles of rural lines has been built in the rural construction program, to which have been attached some 6,000 farm, 25,000 residential, 5,000 commercial and small industrial customers. The usage per rural customer averages 1,650 kilowatt-hours annually, but may be expected to increase rapidly since customers on recently constructed lines first make use of electricity primarily for lighting and later take full advantage of a liberal policy on the purchase of electrical appliances.

A typical rural area showing the coverage of highways in a rural section is shown in figure 2. Practically all roads not supplied by distribution lines have a load density of less than three customers per mile.

Power supply to the rural areas has been planned upon the projection of a number of small automatic substations upon the grid formed by the network of rural lines. Theoretically, such an area would appear as shown in figure 3, resembling in many respects a primary network grid. However, several distinct factors differentiate the plan from a primary network. Three-phase tie lines are generally provided, or are anticipated between substations, these being constructed if, and when such tie lines are economically justified. This construction consists of polyphasing existing single-phase lines, such single-phase lines later to form tie lines having been built of greater conductivity size in anticipation of their future tie-line application. At the present time plans do not contemplate the operation of the tie lines closed, these being operated as radial feeders from each substation. Their main purpose is to provide facilities for emergency feed into an area in the event of a substation failure, or in case of the necessity of taking a substation out of service for routine maintenance. Routine maintenance is necessarily scheduled for off-peak periods. In case of a substation failure during peak periods, lower voltage than normally considered fully adequate would be experienced, but service could at least be maintained. This latter condition has not yet been experienced on our system, and should be relatively infrequent. Future development may show the possibility of operating the rural network as an integrated network, as recently accomplished in a section of suburban Philadelphia.[1,2] Figure 4 shows a portion of such a development showing the location of stations and tie lines.

The locations of substations to supply this rural network are necessarily influenced by a number of factors, as follows:

1. Load density of the area to be supplied.

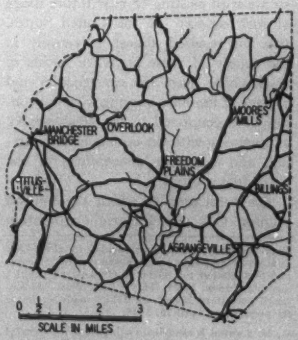


Figure 2. Typical rural area showing coverage of highways

2. Proximity to existing transmission lines. Wherever possible, advantage is taken of existing lines and switching structures in such lines. Substations are tapped through suitable protective equipment to lines of any voltage available, 13.8-, 33-, and 66-kv equipment having been used.

3. Proximity to villages or industrial loads.

Various types of substations have been utilized, the type depending to a great extent upon the following factors:

1. Probable load growth in the immediate area.

2. Possibility of load shift as area is developed.

3. Availability of existing equipment, which may be transferred from some other substation due to necessary changes in that location.

During the early periods of development, when the number of rural lines in an area were limited, a number of two- or three-pole platform structures both with and without regulators were installed. These have mostly been replaced by more adequate equipments, and at the present time there appears to be little need for the use of this type of structure, since it is usually possible to pick up an immediate load of 400 to 500 kw by the time a substation is required in a rural area.

New substations are now installed with a capacity of 750 to 1,000 kva with the possibility of increasing these ratings 25 per cent with air-blast equipment. They are tapped to the transmission line through a manual three-pole disconnect switch and protected on the high-voltage side by means of fuses. Voltage regulation is provided in new transformers through tap-changing equipment. Where existing transformers are available, regulation is supplied by means of step regulators, pole-type or outdoor substation-type induction regulators, or indoor induction regulators rebuilt for outdoor service, the type used depending upon the equipment available.

Where new equipment is required, a unit-type substation has been adopted as standard equipment. The first unit was installed in 1931, and has been followed by the installation of three additional units. The 1938 program calls for the installation of three units, one to be ready for service by the end of May.

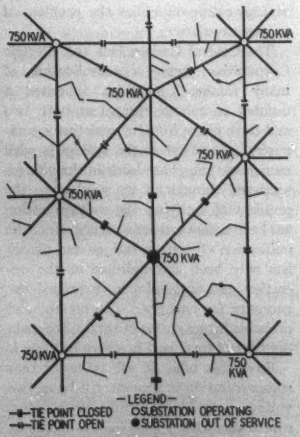


Figure 3. Theoretical rural network showing polyphase tie lines between substations, and operation with one substation out of service

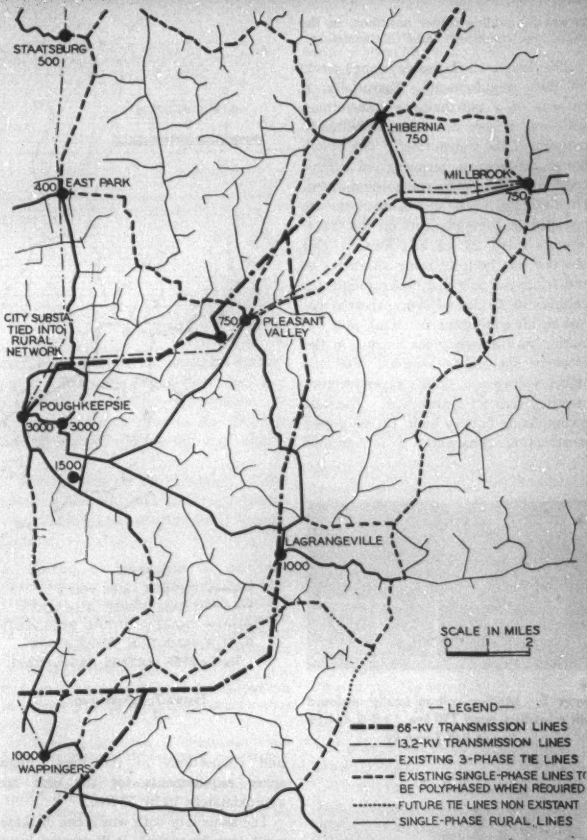


Figure 4. Development of rural network showing substation and tie lines

The essential requisites for a unit substation are as follows:

1. The total installed cost must be low, comparing favorably with the cost of the conventional structure substation.

2. The unit must provide voltage regulation to compensate for transmission and primary voltage drops.

3. It must be inconspicuous, require a minimum of space, and present a minimum hazard from public liability standpoint.

4. The installation cost must be low, thereby providing maximum salvage in the event it becomes necessary to shift the location due to a change in load distribution or development.

5. It must be easily and safely maintained. In the event of breakdown of any piece of apparatus, particularly the transformer, the layout must allow for its ready removal and replacement.

6. The design must provide economical

means for adding feeder positions, in the event load conditions make this necessary.

The design which was developed meets all these requirements. Essentially, it consists of a tap-changing transformer, with one or more switch houses bolted to one side of the transformer. The switch house contains a reclosing oil circuit breaker and load-ratio-control equipment. High-voltage fuses and disconnects are installed in compartments on the transformers rated 23 kv and lower. Our practice has been to bring all cables to and from the pole line underground, for voltages of 23 kv and lower, thereby enclosing all equipment in metal, and obviating any necessity for fencing in the property for safety reasons. For the higher voltages, a simple superstructure permits overhead connections. The unit is completely factory built, the only field construction consisting of foundations and connections to the lines. Floor space requirements for the unit are approximately 10 by 13 feet.[2]

Figure 5. Medium-voltage totally enclosed unit substation, rated 750 kva, 13.8–2.4/4.16 wye/4.8/8.3 wye kv

Figure 6. High-voltage unit substation with superstructure for high-voltage control, rated 1,000 kva, 66–2.4/4.16 wye/4.8/8.3 kv

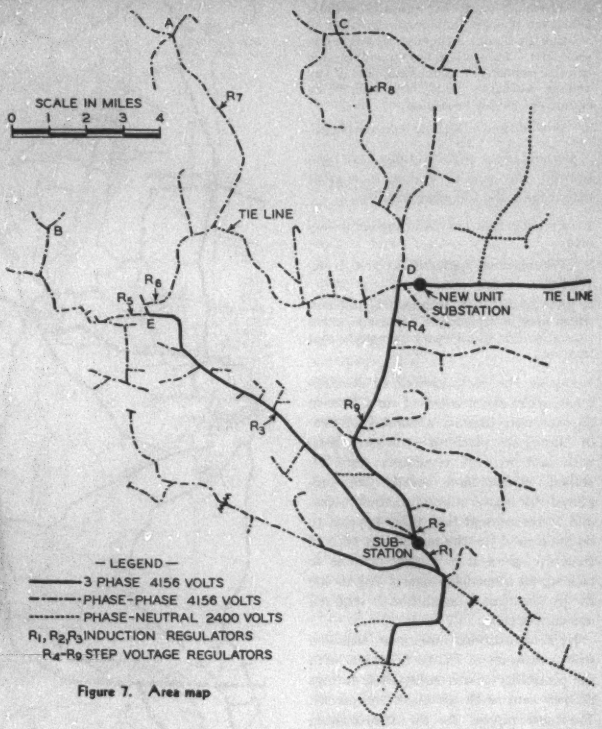


Figure 7. Area map

The simplicity with which one of these units may be moved, is illustrated by a case in which it was necessary to move a 750-kv unit complete with feeder equipment, approximately four miles. The unit was available for operation within two working days, including a change in internal connections from 4,800 volts delta to 4,160 volts wye.

Figure 5 shows a typical unit substation rated 13.8 kv, 750 kva, with all live parts metal clad. Figure 6 illustrates a 66-kv 1,000-kva unit with exposed high-voltage switching on a steel superstructure. The air-break switch on top of the structure and the capacitor on the side have no relation to the unit structure, being automatic sectionalizing equipment for the 66-kv transmission line.

Voltage Rating of Rural Lines

The selection of voltage rating for rural lines is dependent on many factors, and the economics of a voltage rating in one part of the country may well be reversed in others. Obviously, a high voltage rating simplifies the problem of voltage regulation.

The Central Hudson Gas and Electric Corporation, being a consolidation of many smaller companies, inherited a number of voltage ratings at both two and three phase from its predecessor companies. Involved as the system is with numerous polyphase loads in the villages scattered throughout its rural area, the problem of unifying the voltage rating has been a slow and arduous one, since the unification of voltage ratings and phases has only been accomplished as the operation and economics have proved the necessity for changes. The present and probable future status of rural voltages in per cent of total load is shown in table I.

From this table, it will be noted that standardization in general will be at two voltages; 4,160-volt, three-phase, four-wire mains with single-phase branches at 2,400 volts phase to neutral and 4,000 volts phase to phase, 4,800 volts single and three phase. A limited area will, in

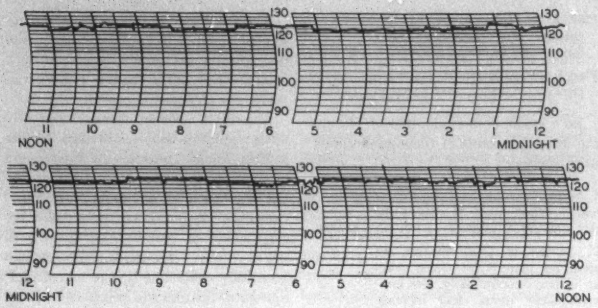


Figure 8. Typical 24-hour chart—primary voltage at point A

all probability, remain at 8,320 volts, three phase, four wire, with branches at 4,800 volts phase to neutral, or at 2,400 volts phase to neutral, the reduction in voltage being obtained through 2:1 autotransformers.

It will be noted that the company's experience has covered a wide range of voltages. Beginning initially with 2,400-volt two- and three-phase systems, conversions were made first to 2,400/4,160 wye operations, and at a later date to some 4,800-volt systems. A trial installation at 4,800/8,320 wye was also made. This has been successfully operated, but was found to have definite operating disadvantages for conditions encountered in our particular area. For sparsely settled areas where clearances from trees can be readily obtained, and where economic joint usage with communication facilities can be satisfactorily negotiated, there appears to be a distinct field for its application.

Consideration of the factors involved in the analysis of our rural problem has led us to the conclusion that the most satisfactory voltage for rural distribution in our area is 2,400/4,160 wye volts, three phase, four wire with common-neutral multiple-grounded construction. However, since some of our areas are operating at 4,800 volts, delta, there does not appear to be sufficient justification for conversion of such areas to the common neutral system. Hence the dual standard.

Table I. Distribution of Rural Voltage Ratings

Voltage Rating	Present: Connected Kilovolt-amperes	Present: Per Cent of Total	Ultimate Per Cent of Total
2.4 kv, three phase delta	3,571	6.4	...
2.4 kv, two phase	4,721	8.5	...
4.2 kv, three phase wye	32,196	58.3	72.0
4.8 kv, three phase delta	11,977	21.8	25.0
6.2 kv, three phase wye	1,460	2.6	...
8.3 kv, three phase wye	1,333	2.4	3.0
Total	55,258	100.0	100.0

The decision on the adoption of the common neutral 2,400/4,160 wye system was primarily based upon the following factors:

1. Spacing of substations in the fully developed plan will provide rural feeders of reasonable length for adequate primary regulation, especially with the judicious use of step regulators and shunt capacitors in providing economical and satisfactory means of voltage control.

2. Advantages of a common-neutral system in obtaining better operating characteristics in:

(*a*) Lightning protection of distribution transformers as shown by the analysis of outages from this cause.

(*b*) Low ground resistance of the neutral wire through multiple grounding.

(*c*) Simplification of all line and transformer devices.

(*d*) Improvement in sectionalizing and branch fuse operation.

3. Safety in live-line maintenance, due to voltage being well within the safe operating range of standard rubber goods.

4. Minimum of trouble due to tree interference. This factor is particularly important in this region, due to the difficulty of obtaining permission for ample clearances from trees in a territory prolific in its abundance of large and old trees. The common-neutral system also permits the economical use of cable construction through the use of self-supporting cable or cable supported on a neutral conductor messenger where tree conditions prevent successful operation of tree wire.

5. Economic analysis indicates that this system can be used at costs comparable with systems of higher voltages.

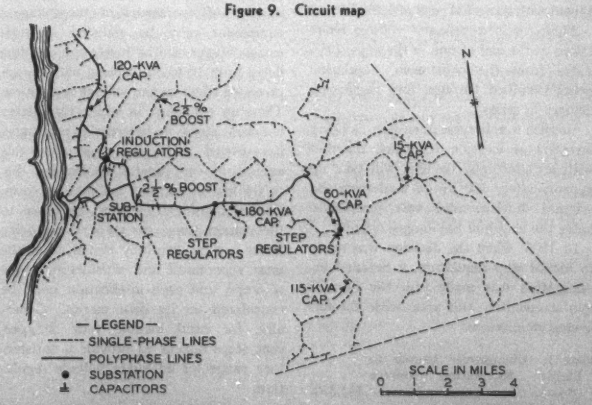
Development of a Rural Area

In the development of a rural area, it is by no means unusual to attach rural lines of extreme length to a substation supply source. During the initial period, the loading on these lines may be extremely light, gradually increasing with the attachment of additional customers and the further utilization of the service. The development of low-cost regulating equipment has materially increased the time limit before additional reinforcement becomes essential. The use in particular of step regulators and automatic boosters may lengthen the period of adequate regulation on a rural circuit for years. One of the big advantages of this class of equipment is that the cost of installation is a small percentage of the total cost and a large part of the cost in equipment is salvageable.

Thus it may be economical to use regulating devices on the lines to furnish temporary relief for any one of the following reasons:

(*a*) To allow further study to be made to

Figure 9. Circuit map



determine the most desirable and economical permanent solution.

(*b*) To allow further development of the area supplied before definite plans are put into effect which may be affected by these developments.

(*c*) To delay the expenditure necessary to accomplish the ultimate plan until economically warranted.

These points are, of course, interrelated and whichever may be the primary reason for the use of regulating devices, the other advantages will be gained.

A description of such a development in one of our rural areas has been presented previously[4] but it may be of interest to trace the development through its successive stages.

Figure 7 shows the area under discussion. Originally supplied at 2,400 volts single phase, lines were extended and supply reinforced through the following stages:

Polyphase of main stems at 2,400 volts (1924–26)	peak load 250 kw
Conversion to 4,000 volts (1927)	peak load 325 kw
Addition of two pole-type induction regulators and several fixed boosters (1929–34)	peak load 700 kw
Relocation of existing regulators and additions of six step regulators, resulting in four step regulators in series on one feeder (1935)	peak load 750 kw

The addition of step regulators in 1935 was estimated to provide regulation for the system through 1937 for an estimated peak of 950 kw. Actually, with the installation of an additional polyphase step regulator installation on one of the branches, adequate voltage was maintained with an actual peak of 1,100 kw.

Figure 8 is a primary voltage chart taken at the end of one of the lines, 19½ miles from the substation, regulation being obtained through four regulating devices in series.

In 1938 a unit-type substation is being installed at location *D*, which together with an additional tie line, will take up approximately 500 kw of load from the original station, and will practically halve the length of the longest circuits.

In 1935, when the decision was made to install step regulators, a detailed investigation was made into the cost of reinforcement to this area, with the following comparison:

Plan 1. Changeover system to higher distribution voltage (8 kv)	$45,350.
Plan 2. Additional 13.2-kv substation, and necessary transformer and feeder extension	40,500.
Plan 3. Installation of step regulators and feeder reinforcement	15,700.

As a result of the adoption of plan 3, the following points of economic interest were obtained:

1. Investment not salvageable or useful when plan 2 would be essential for capacity	$3,000.
2. Saving in fixed charges by adopting plan 3 for three years at 12 per cent annually, less non-salvageable items, less increase in losses due to adoption of plan 3	4,400.

The adoption of the step regulator plan was not only the most economical but also postponed the necessity of making a much larger immediate investment, and gave three additional years for the region to develop so that advantage could be taken of changes in load distribution in the area.

Voltage Control and Regulating Devices

No attempt will be made here to present the technical details of operation, or the theoretical limits of applications, as this subject has been fully covered in numerous papers previously.[5–7] A brief outline of the devices available, and their adaptability to rural-line application appears in order.

For strictly rural load, consisting mainly of a multiplicity of comparatively small individual loading devices, the use of high-speed devices for following small voltage fluctuations appears to be unnecessary. A number of tests on the effect of time delay conducted on our regulating devices indicate that the number of operations of tap-changing equipment may be reduced approximately 80 per cent by increasing the time delay from 10 to 30 seconds, with no appreciable effect on the voltage regulation. The step regulator, in which time delay between steps is inherently necessary, has proved to be the most adaptable equipment for general application due to its low initial and installation costs. Careful consideration must be given to the voltage range per step. No specific limits can be definitely stated as to the most economical and satisfactory range of steps, and each application must be considered on its own merits. Generally, for rural loading four 2½-percent steps appear to provide a satisfactory range for adequate voltage regulation.

The automatic step booster has a very limited application for rural loading, and its application is usually dependent upon comparatively large changes of load connected for appreciable periods of time.

The fixed booster, though obviously not a regulating device, still has a definite field in voltage control. By their use, a line can be controlled to have practically flat regulation at minimum load conditions, and such use has practically the same effect as obtained by increase in size of copper. The amount of boost can be readily controlled by the use of multiple-ratio distribution transformers, and if a standard make transformer rated 2,400/3,600/4,156/4,800–120/240 volts is used, voltage boosts of 2.5, 2.88, 3.33, 5.0, 5.76, 6.66, and 10 per cent may be obtained on a 2,400-volt primary line.

The application of shunt capacitors for voltage control on rural lines has little justification, except where it is possible to make use of the advantages obtained by the capacitor in releasing substation transformer or transmission-line capacity, or in system power-factor correction. The low installed cost of distribution capacitors compares favorably with the installed cost of reasonably large rotating equipment, and where a certain fixed amount of capacity may be economically used at all times, distribution capacitors with their much higher efficiency, may readily be justified. The amount of voltage control supplied by these devices being fixed within narrow limits (two to three per cent on rural lines), they must

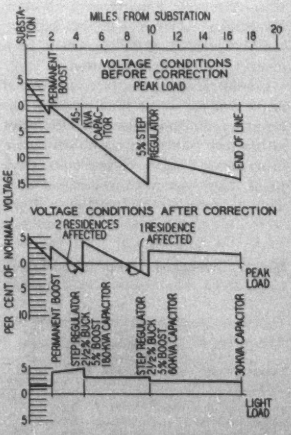


Figure 10. Application of voltage-corrective measures following graphic instrument survey of rural-line loading and regulation

be applied with the same caution as the fixed booster.

The series capacitor can rarely be applied for rural-line regulation. Depending upon the elimination of the reactance drop by insertion in the line of a capacitive reactance equal to the inductive reactance of the line, its purpose is defeated by the large resistance component of the average rural line. Elimination of the reactance drop is insufficient as shown by table II.

By overcompensating, part or all the drop due to resistance can be balanced out at any power factor other than unity. At high power factors, this requires an unreasonable amount of capacity. The series capacitor may be compared to an instantaneous regulator set to maintain a fixed voltage at some load center (assuming the supply voltage constant). It is subject to limitations where customers are distributed along the line in that any decrease in drop effected for the last customer on the line is accompanied by a corresponding increase for the first customer. This can be overcome by splitting the capacity up in small-size units, but only at prohibitive cost.

Except in those cases where instantaneous regulation is required to overcome a flicker condition or where lines are used to feed a load at some distance with no intervening load, some other one or combination of devices will give more satisfactory or economical results than the series capacitor.

Voltage Surveys

In order to keep a constant control of voltage conditions throughout the territory, a program was started several years ago of installing permanent voltage-recording stations attached to the primary lines through individual potential transformers. Completion of this program is expected during 1938. The location of each of these test stations is carefully checked to provide a close control and indicator of the voltage and load trend.

In addition, a plan of conducting periodic surveys of all load areas has been instituted. This survey covers the procurement of a complete series of simultaneous graphic records of voltages over the entire area, coupled with graphic ammeters at pertinent points for loading and load balance, and graphic watt-meters and reactive-volt-ampere meters for circuit loading. These charts, assembled and pasted together, show simultaneous readings all over the circuit, and readily reveal the necessity for load balance, reinforcement, correction for regulator settings, and improvements which may be effected through the use of additional boosters, step regulators, and shunt capacitors. This recording is continued until corrective measures have been applied and reasonable assurance is obtained from graphic records that voltage conditions will continue to be satisfactory. In conducting such a survey 20 to 30 graphic voltmeters are utilized, these instruments being calibrated in the field after warming up in location, a high-grade voltmeter with low temperature error being used for this calibration.

An illustration of the effectiveness of this field survey is shown in an area which had built up very rapidly in rural extensions, and which had not received a previous check of the type described. Figure 9 shows the area in question and figure 10 shows the voltage conditions before and after voltage conditions were corrected. In this case four additional step regulators and 165 kva in shunt capacitors, provided adequate relief from the serious voltage difficulties encountered. Further improvement to this area, contemplated several years previously, will be provided when the fringes of this area can be transferred to a new unit substation to be installed in 1938.

Conclusions

The necessity of reliable rural lines with adequately controlled and regulated voltage has been shown to be essential for the type of service requirements. Voltage rating is dependent upon many factors, and reliability and freedom from interruptions must be considered along with voltage rating. With the equipment now available, voltage can be accurately regulated over substantially long lines at reasonable cost, and frequently major expenditures for reinforcement can be deferred for long periods by the proper application of regulating equipment. The field for application of step regulators is large and due to the low installation cost may be justified in many cases for temporary relief. The application of shunt capacitors is more restricted on rural lines where resistance drop may be a large portion of the total drop, and cannot be justified for voltage regulation alone, but may be used where interrelated savings in substation capacity or system power-factor improvement aid in the justification of their use. Series capacitors appear to have little application for general rural use, and their justification is dependent on special applications usually in conjunction with motor loads.

Table II. Voltage Drop on Four-Kv Three-Phase Line

Copper Wire Size	Volts Per Ampere Per Mile at 85 Per Cent Power Factor		
	Due to Resistance	Due to Reactance	Total
2	.66	.38	1.04
4	1.17	.39	1.56
6	1.67	.40	2.07

Rural electrification, being still in its infancy with respect to utilization, requires continual and careful study and checking of load growth, circuit balance, and voltage regulation to the end of producing greater satisfaction among its users, increased revenues from adequate regulation, and stimulating the further utilization of the service available.

References

1. Modified Primary Network Brings Low-Cost Reliability, *Electric Light and Power*, September 1937.

2. Transmission Tapped for Distribution by New Unit, G. S. Van Antwerp and H. S. Warford. *Electrical World*, January 1, 1938.

3. Rural Substation Developed to Meet Seven Requirements, G. H. Landis. *Electrical World*, July 2, 1932.

4. Step Regulators Avert Large Rural Outlay, G. H. Landis and H. A. McLaughlin. *Electrical World*, August 14, 1937.

5. Regulation Beyond the Distribution Substation, P. E. Benner. Electrical Engineering, August 1935.

6. Automatic Boosters on Distribution Circuits, L. M. Olmsted. Electrical Engineering, October 1936.

7. Why Not Series Capacitors for Distribution Feeders? C. L. Dudley and E. H. Snyder. *Electrical World*, June 30, 1934.

Voltage-Regulating-Equipment Characteristics as a Guide to Application

By P. E. BENNER
ASSOCIATE AIEE

G. S. LUNGE
ASSOCIATE AIEE

Synopsis: In addition to being based on economic factors, the application of voltage-regulating equipment to systems should take into account its characteristics and inherent limitations. These characteristics include operating speed, sensitivity, suitability for parallel operation and for frequent voltage-correcting action, how affected by the load power factor and by line constants, ability to compensate for supply-voltage variations, effect on wave form, etc. The majority of systems need both generator voltage regulators and suitable feeder regulators, if maximum ease, efficiency, and flexibility of system operation are desired. Proper choice and adjustment of the voltage-responsive controlling elements of such regulating equipment will insure harmonious functioning of the regulators throughout the system, without hunting between regulators of different construction.

THE selection of voltage-regulating equipment involves two classes of problems. The first of these is technical, and concerns itself with the characteristics of the various available classes of regulating equipment with their corresponding limitations. The second problem is economic and is concerned with finding the least expensive solution to the problem of maintaining adequately constant voltage. The economic problem predominates in the application of voltage-regulating equipment to the distribution system,[1] as distinct from the generating and transmitting portion of the system. As far as the technical characteristics of voltage-regulating equipment are concerned, it might be felt that these are too well recognized to require further consideration at this time. However, instances frequently occur of misapplication of regulating equipment due to disregard of the inherent limitations of the types of regulating equipment concerned, usually because insufficient consideration has been given to the analysis of the causes of the poor voltage conditions which it is desired to correct.

As here used, the term "voltage-regulating equipment" signifies not merely the voltage regulator itself but also the associated apparatus such as for example, a synchronous condenser when controlled by an automatic voltage regulator.

Only equipment that functions automatically is here considered.

As above defined, voltage-regulating equipment is subjected to supply-voltage variations due to transient conditions such as those caused by faults and also to those produced by slow or rapid load changes. (By load changes are meant not only changes in the amount of steady load connected, but also noncyclic, abrupt changes in load impedance, such as may result from the starting of large motors connected with the circuit and from similar causes.) Voltage-regulating-equipment performance during fault conditions and its effect on stability[2,3,4] will not be discussed here, nor will the subject of voltage variations due to cyclic changes be discussed at this time.

Progress in industrial and domestic electrification has gradually imposed added requirements upon the quality of electric service, such as the present-day insistence on maintenance of sufficiently constant frequency for electric-clock operation. Fortunately, however, this tendency toward more exacting electric-service requirements is to some extent compensated for by the improvement of apparatus. For instance, the advent of adequate generator voltage regulators made it possible to discontinue insisting upon small natural voltage regulation as a generator design requirement. This change makes it possible for generator designers to emphasize other more important characteristics of their machines. It is believed that by proper application of voltage-regulating equipment to a system, the range of taps required in transformers can be kept within economical limits, thereby reducing the investment in what would otherwise be special power transformers. Also maximum freedom in system operation is afforded so that the voltages at different points on the system can be held at the most appropriate values from the standpoint of minimizing transmission line losses and keeping the power factor within the desired limits in interconnecting lines.

Classification of Voltage-Regulating Equipment

Voltage-regulating equipment may be classified on the basis of the manner in which it functions, as shown in table I.

As used in this tabulation, the term "generator voltage regulator" means, according to a proposed standard definition, "a regulator which functions to maintain the voltage of a synchronous generator, condenser, motor, or of a d-c generator, at a predetermined value, or vary it according to a predetermined plan."

The question of whether extensive use should be made of generator voltage regulators in preference to the use of feeder voltage-regulating devices sometimes arises, but except in special cases of systems of very limited extent, a definite choice between the two types of equipment should rarely be necessary. Generator voltage regulators are, by virtue of their construction, usually better suited to rapid and frequent operation than are feeder voltage regulators, if maintenance of the latter is to be kept within reasonable limits. Generator voltage regulators are, however, electrically farthest away from individual

Table I

(*A*) Voltage-correcting equipment (corrects for supply-voltage variations)	
(*a*) Direct (series) correction	
Varying excitation (generator voltage regulator)	(1)
Varying voltage ratio	
I. With major change in voltage level (Load-ratio-control transformer)	(2)
II. Without major change in voltage level	
A. Smooth changes	
(Station-type induction regulator)	(3)
(Branch-feeder induction regulator)	(4)
B. Changes by steps	
(Regulating transformer)	(5)
(Station-type step regulator)	(6)
(Branch-feeder step regulator)	(7)
(Branch-feeder booster)	(8)
(*b*) Indirect (shunt) correction	
(Synchronous condenser with voltage regulator)	(9)
(Shunt capacitors with voltage-regulating relay)	(10)
(Shunt reactors, in blocks, with voltage-regulating relay)	(11)
(Shunt reactors with saturating windings)	(12)
(*B*) Voltage-drop compensating equipment (does not correct for supply-voltage variations)	
(*a*) Direct (series) compensation	
(Series capacitors)	(13)
(Series reactors with saturating windings)	(14)

Paper number 38-46, recommended by the AIEE committee on power transmission and distribution, and presented at the AIEE North Eastern District meeting, Lenox, Mass., May 18–20, 1938. Manuscript submitted February 19, 1938; made available for preprinting April 27, 1938.

P. E. BENNER and G. S. LUNGE are both in the engineering division of the central station department, General Electric Company, Schenectady, N. Y.

1. For all numbered references, see list at end of paper.

loads responsible for fluctuations in the voltage. Thus there appears to be little relationship between the speeds of operation of these devices and the duty ordinarily imposed on them. This dilemma can be avoided by proper adjustment of the sensitivity of the voltage-responsive control elements of the generator and feeder voltage-regulating equipment, respectively. In general, it may be said that:

1. The need for rapid correction of the voltage in case of major system load changes makes generator voltage regulators essential for most systems.

2. The value of generator voltage regulators in limiting overvoltage in case of sudden loss of load is now well recognized.[5]

3. The impracticability of applying line-drop compensating schemes to most systems to permit generator voltage regulators to hold constant voltage at a remote distribution center makes feeder regulators desirable.

4. The diversity of feeder lengths and loading makes the application of individual feeder regulator equipment of appropriate type essential to good voltage conditions at the load.

It is hoped that a brief discussion of the comparative characteristics of each of the voltage-regulating equipment types mentioned in table I will be of assistance to anyone faced with the problem of choosing between the available means for solving this problem.

Generator Voltage Regulators (1)

These regulators are best suited to holding constant voltage at the low-voltage or high-voltage generating station bus. Although it is possible to use line-drop-compensating schemes to hold constant voltage at the remote end of a transmission line, there are very few cases in which as much line-drop compensation as this is used. The basic reason for this is that changing load and generating conditions on a system make it desirable to hold different voltage levels at different points on the system at various times of the day. Compensating for all of the transmission-line voltage drop makes it difficult to control the division of reactive power between different generating stations and is comparable to attempting to operate two generators, each under voltage-regulator control, connected to the same bus without having the usual provision for eliminating excessive reactive-current interchange between the two generators.[6] The use of motor-operated voltage-adjusting rheostats for generator voltage regulators in unattended stations makes it possible to adjust the voltage levels held at such stations by means of supervisory control just as readily as the kilowatt load on units in such unattended stations can be adjusted.

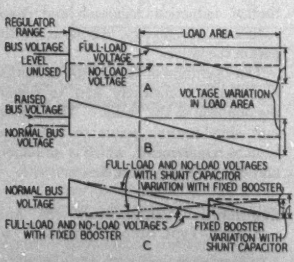


Figure 1. The induction regulator inherently has a lower as well as a raise range. Full use can be made of the total range by the proper selection of substation bus voltage (B) or by the use of a fixed boost in the feeder circuit (C). Shunt capacitors produce a voltage rise, and in this case if the voltage rise produced by the capacitor equals the lower range of the regulator, full use can be made of the full regulator range with minimum voltage variation in the load area

In special cases, current limiting relays have been used in conjunction with generator voltage regulators, but it should be recognized that any such supplementary equipment may impair the normal regulator performance during transient conditions. Some use has also been made of power-factor regulators, especially when applied to generators of relatively small size located electrically close to much larger stations, with a view to avoiding attempts on the part of the small machines to change the voltage level of the larger systems and in so doing overload themselves. The use of such power-factor regulators would seem to be extremely limited and ordinarily requires supplementing by the use of a conventional voltage regulator in order to take control away from the power-factor regulator in case of faults on the system. The low power factor of most faults would otherwise cause the power-factor regulator to reduce the generator excitation, which is just the opposite to what is required under these conditions.

The use of generator voltage regulators relieves the station operator of the need for frequent adjustment of the excitation; if there are no generator voltage regulators, the only alternative is to leave sufficient excitation on the machine to insure reasonably stable operation under any anticipated load condition. This additional excitation will result in added losses and heating of the machine.

Although generator voltage regulators are, in general, rapid in action, it should be realized that even if there were no time delay at all in the operation of the regulator, it could not possibly cure light flicker in the case of voltage fluctuation sufficiently widespread to appear at the generator terminals. The first drop in voltage occurs instantaneously, but can only be corrected at a finite rate in accordance with the time constant of the a-c machine. Other methods of mitigating light flicker should be considered instead.[7]

Load-Ratio-Control Transformers (2)

Although originally chiefly used in transmission-line loop circuits and in tie-lines interconnecting different systems, increasing recognition is being given to the suitability of load-ratio-control equipment for maintaining approximately constant voltage at a bus whenever this can be accomplished by ratio change. In general, the load-ratio-control equipment is not intended for very frequent operation, in the interest of reducing maintenance on the tap-changing equipment. Accordingly, the automatic relay equipment ordinarily includes time-delay relays to insure that the departure from normal voltage must persist for a definite time before any attempt is made to correct it.

Station-Type Induction Regulator (3)

The characteristics of the direct or series regulating device used for feeder regulation are a combination of the inherent characteristics of the equipment itself and the control with governs its operation. The design, adjustment and therefore the characteristics of the control are largely determined by the limitations of the device.

In the direct or series devices, the ratio of incoming to outgoing voltage is varied by changing the ratio of $\phi_1 N_1/\phi_2 N_2$. This is accomplished by changing the turn ratio N_1/N_2 in the case of step regulators and load-ratio-control transformers or by changing the flux ratio ϕ_1/ϕ_2 in the case of induction regulators.

The induction regulator is controlled by the same voltage-regulating relay as a load-ratio-control transformer but its response is instantaneous rather than delayed because of the fact that it can stand the duty of making frequent voltage corrections.

The characteristics of the regulated

voltage and therefore of the device itself are determined by the setting of the voltage-regulating relay and the line-drop compensator. The voltage-regulating relay is sensitive and responds to changes in voltages of only a fraction of a per cent. To take full advantage, as far as regulated voltage is concerned, of the sensitivity of the voltage-regulating relay would result in almost continuous operation of the induction regulator due to the continual variation in the incoming supply of voltage. It has been found practical to adjust the voltage-regulating relay used with induction regulators to initiate corrections when the voltage variation exceeds one per cent from the desired level. This constitutes a total band width of two per cent. Corrections would be small and very frequent except for the fact that the voltage-regulating relay is equipped with holding coils which, when the correction is initiated, hold the contacts closed until the voltage is corrected to approximately the center of the band. This holding adjustment of the voltage-regulating relay for induction-regulator control differs from that for step regulators in that with step regulators only sufficient holding is used to insure successful contact operation.

The induction regulator responds immediately when the control initiates a voltage correction, with the result that, except for instantaneous fluctuations, the regulated voltage is kept within the band setting. This is an important characteristic of induction regulators and should be evaluated on the basis that any decrease in variation of regulated voltage

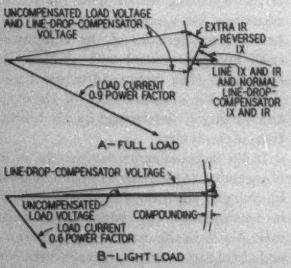

UNCOMPENSATED LOAD VOLTAGE AND LINE-DROP-COMPENSATOR VOLTAGE
EXTRA IR REVERSED IX
LINE IX AND IR AND NORMAL LINE-DROP-COMPENSATOR IX AND IR
LOAD CURRENT 0.9 POWER FACTOR
A—FULL LOAD
LINE-DROP-COMPENSATOR VOLTAGE
UNCOMPENSATED LOAD VOLTAGE
COMPOUNDING
LOAD CURRENT 0.6 POWER FACTOR
B—LIGHT LOAD

Figure 2. Reducing or even reversing the reactance compensation is an effective method of stabilizing regulators operating in parallel where reactance constitutes a large part of the impedance of the circulating path and the circulating current is therefore largely reactive. Increasing the resistance setting to offset the reduced reactance setting will have a compounding effect as shown if the power factor is higher at full load

permits an increase in the allowable drop in the load area for certain given maximum and minimum voltages on customers' premises.

Single-phase induction regulators are basically different from three-phase induction regulators in the manner of varying voltage. In the single-phase induction regulator the voltage induced in the series winding varies from a maximum value to zero and is always in phase with the excitation of the shunt winding. The fact that no voltage is induced in the series winding of a regulator at a certain position of the rotor makes it possible to by-pass the series winding when switching the regulator in or out of service. The fact that the induced voltage is in phase makes parallel operation feasible. The three-phase regulator, on the other hand, varies voltage by changing the

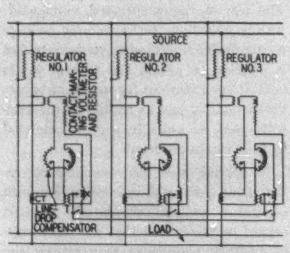


Figure 3. The use of paralleling reactors (X) inserted in the contact-making voltmeter circuits by means of insulating transformers (T) is an effective method of paralleling regulators in the same station. This scheme also requires a low-power-factor circulating current for successful operation, but it has the advantage of permitting the line-drop compensator settings to match the characteristics of the feeder circuit

phase of a constant series voltage through 180 degrees. By-passing three-phase regulators requires paralleling with another similar three-phase regulator set in the same relative position, or the use of impedance to limit the circulating current when the series winding is short circuited. Except in the maximum raise or lower position, the three-phase induction regulator displaces the phase of the regulated voltage and parallel operation requires the use of some means for keeping the rotors of the regulators in the same relative position. This has been accomplished by mechanical connection or by the use of Selsyns.

One method of eliminating phase displacement in three-phase regulators that is used occasionally is the interconnection of two three-phase regulators in such a way that the phase displacement of one is compensated for by an equal and opposite phase displacement in the other.

It is inherent in the design of the induction regulator to have a lower as well as a raise range. Full use can be made of the total lower and raise range by properly selecting the substation bus voltage with the aid of transformer taps or by the use of a fixed boost in the feeder circuit as shown by *B* and *C*, figure 1. The installation of shunt capacitors for power-factor correction produces a voltage rise in the feeder circuit as shown by figure 1 *C*, and like a fixed boost enables the full use of the lower and raise range of the regulator without raising the substation bus voltage, providing the voltage rise produced by the capacitor equals the lower range of the regulator.

Branch-Feeder Induction Regulator (4)

The small single-phase induction regulator (12 and 24 kva, 2,400 and 4,800 volts) especially designed for pole mounting has the same general characteristics as the station-type induction regulator. Utilizing the same control, it is capable of the same precise voltage regulation. This characteristic makes it suitable for use on main circuits serving important loads. Being designed to supplement the station induction regulator on long heavily loaded branches or to compensate for voltage drop in the load area, the branch-feeder induction regulator operates more slowly than the station regulator. In case of simultaneous operation, the station regulator will make its corrections very rapidly in comparison to the branch induction regulator and eliminate any unnecessary operation on the part of the latter.

The operation of the branch induction regulator is sufficiently slow to permit the omission of the brake. This important simplification points to low maintenance requirements, which is an important characteristic of the device.

Regulating Transformers (5) and Station-Type Step Regulators (6)

The characteristics of a regulating transformer are identical with those of a load-ratio-control transformer as far as correction of voltage is concerned. It is a question of transformer design as to whether load-ratio-control features should be provided in the power transformer used for producing the major change in voltage levels, or, alternatively, to build the main transformer as a fixed-

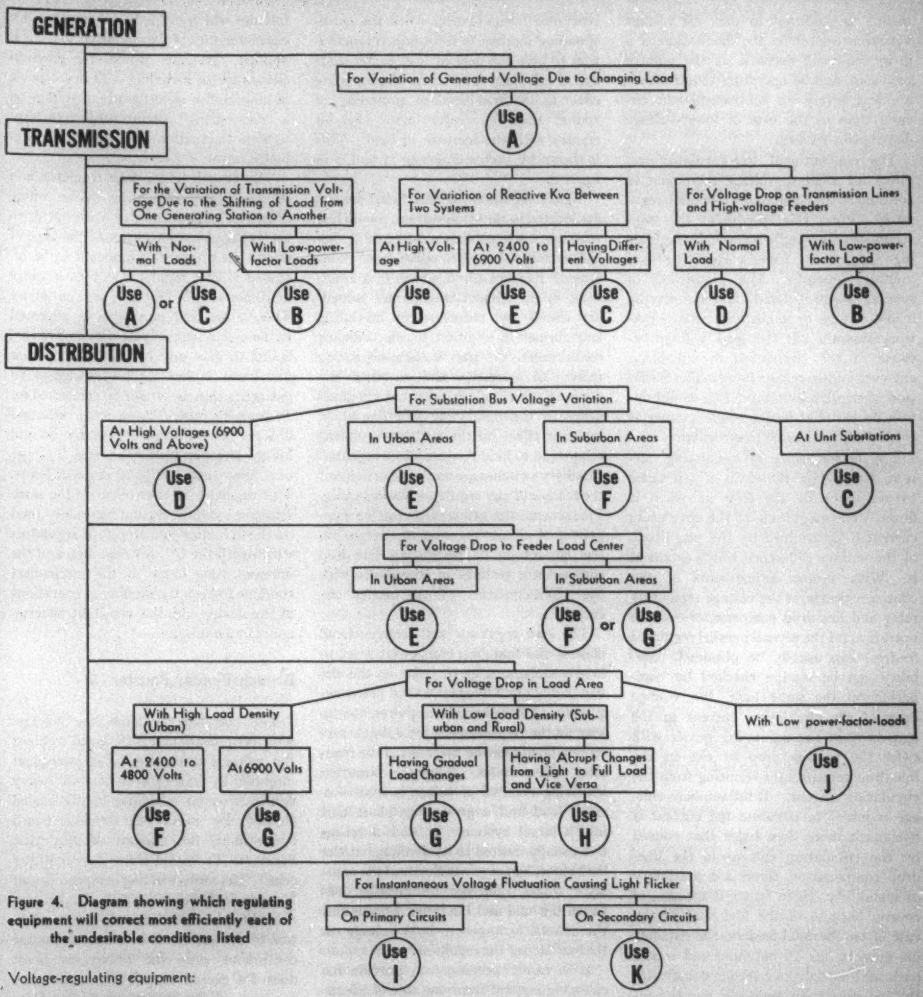


Figure 4. Diagram showing which regulating equipment will correct most efficiently each of the undesirable conditions listed

Voltage-regulating equipment:

A—Generator voltage regulators
B—Synchronous condensers
C—Transformers with tap changing under load
D—Station-type step regulators
E—Station-type induction regulators
F—Branch-feeder induction regulators
G—Branch-feeder step regulators
H—Branch-feeder boosters
I—Series capacitor
J—Shunt capacitor
K—Autotransformer

ratio transformer, all regulating to be performed by load-ratio-control equipment in a regulating transformer. The latter type of transformer is also applicable where there is no question of any major change in voltage level but where a variable voltage ratio between two circuits of the same nominal voltage is desired for voltage regulating purposes. Changing the voltage ratio of the regulating transformer and the station-type step regulator, as previously pointed out, is accomplished by changing the turn ratio. This, of course, involves a switching operation of the tap-changing mechanism. Recognizing contact wear and mechanism life as functions of the number of operations, all manufacturers of step-type regulators recommend delayed response to reduce the number of operations and so obtain reasonable maintenance expense. Increasing the band width of the control likewise reduces the number of operations. Either of these expedients to reduce the number of operations results in increasing the variation of regulated voltage.

In the regulation of higher-voltage circuits (6,900 volts and up) the lower cost of the step-type regulator usually is more important than the closer regulation obtainable with induction-type equip-

ment. In addition to this, the voltage variation caused by the fluctuation of a given load will decrease as the voltage increases, and so operating requirements are less severe on subtransmission circuits than in the case of lower-voltage distribution feeders.

The conventional step-regulator produces an in-phase voltage correction, in contrast to the three-phase induction regulator. From this standpoint the step-regulator is especially suitable for regulating high-voltage feeders supplying low-voltage networks. The paralleling of several step-regulated feeders serving a low-voltage or a medium-voltage network smooths out the load voltage because of the circulation of equalizing currents and so results in a smaller variation of regulated voltage than would obtain on a radial feeder whose voltage is controlled by a similar step regulator.

The power factor of circulating current depends on the ratio of resistance to reactance in the loop in which it flows. The magnitude of the circulating current is determined by the magnitude of the voltage difference which produces it. With proper adjustments of the control—that is, of the voltage-regulating relay and line-drop compensator—stable operation (of the several parallel regulated feeders) can usually be obtained. Stability can be readily checked by comparing on the same base, the voltage drop of the circulating current in the loop beyond the regulating device with twice the voltage drop or rise in the line-drop compensator resulting from the circulating current. If the in-phase voltage required to circulate the current is not much more than twice that caused by the circulating current in the line-drop compensator, there is a possibility of instability. The factor 2 appears, of course, because of the fact that in the case of two parallel feeders, the circulating current has an outgoing and return path and as only one feeder constitutes the outgoing path and only one the return path, the circulating current would affect only two line-drop compensators. Obviously the greater the uncompensated impedance in the circulating path, the more stable will be the operation.

In cases where stable operation is difficult to obtain, several possible expedients may be considered. The simplest of these is to decrease or reverse the reactance element in the line-drop compensator. This is effective where reactance constitutes a large part of the impedance of the circulating path and the circulating current is therefore largely reactive. Decreasing or reversing the reactance compensation (with the corresponding increase in resistance compensation to give the desired load-center voltage at full load) results in a compounding effect as the load increases, providing, of course, that the power factor also increases with the increase in load. This is shown by vector diagrams *A* and *B* in figure 2.

Where regulators of paralleled feeders are located in the same station, paralleling reactors, such as shown in figure 3, can occasionally be used to advantage. This scheme requires the insertion of a reactance in the current transformer secondary circuit by means of an insulating transformer in addition to the ordinary connections of the voltage-regulating relay. In operation the reactive element of the circulating current produces drops in the paralleling reactors which by their effect on the voltage-regulating relay tend to hold the regulators together. Auxiliary switches are used to short-circuit the reactor of any regulator not in service. This scheme also utilizes the reactive component of circulating current, but it has the advantage of permitting line-drop compensator settings in accordance with the characteristics of the feeder circuits.

The step regulator with conventional control and line-drop compensator set to hold voltage at a given point on the circuit will hold voltage at that point regardless of the direction of power flow so long as the requirements for voltage correction do not exceed the range of the regulator. The most frequent situation involving reversal of power is that of a small load and a generating plant tied into a larger system. In such a set-up it is usually desired to hold voltage at the load regardless of power flow and the regulator would therefore be installed between the load and the larger system and the control arranged to hold voltage on the load side of the regulator.

It is rarely necessary to provide for changing control from one side of a regulator to the other. This is required only when the reversal of power is caused by a complete reversal of the principal load and the principal source of power. In installations of this type the voltage-regulating relay is usually switched from one line-drop compensator to another so that different settings may be used for the two different operating arrangements.

Branch-Feeder Step Regulator (7)

There is but little justification for installing a device having operating characteristics which excel the inherent voltage characteristics of the circuit on which it is applied. In other words, the practical advantage of installing a device capable of making fine adjustments in voltage on a "shoe string" circuit subject to large sudden fluctuations in voltage is negligible.

The branch-feeder step regulator is a supplementary regulating device whose operating characteristics correspond to the voltage characteristics of the type of circuit on which it is intended to be installed. This regulator covers a range of 10 per cent in four $2^1/_2$ per cent steps. This 10 per cent range can be allocated by means of an easily accessible terminal board to give any combination of raise and lower within the total range of 10 per cent; that is, it can be connected for 10 per cent raise, $7^1/_2$ per cent raise and $2^1/_2$ per cent lower, 5 per cent raise and lower, $2^1/_2$ per cent raise and $7^1/_2$ per cent lower, and finally 10 per cent lower. This regulator is controlled by the same sensitive voltage-regulating relay used on the induction and step-type regulators which with the $2^1/_2$ per cent step and the inherent time delay of the mechanism combine to keep the number of operations of the device and the resultant maintenance at a minimum.

Branch-Feeder Booster (8)

The one-step regulator has voltage-sensitive control and is designed to boost the voltage automatically at infrequent intervals to take care of periodic heavy demands on an otherwise lightly loaded circuit. By means of terminal board connections, the amount of automatic boost can be varied from $2^1/_2$ to 10 per cent. The series winding is tapped in four $2^1/_2$ per cent sections which can be connected to give a continuous boost in addition to the automatic boost as long as the continuous plus the automatic boost does not exceed 10 per cent. Also, the winding can be connected to lower instead of raise the voltage or to provide any combination of continuous raise or lower plus an automatic raise or lower within the range of the series winding.

A one-step device allows the use of a two-position control instead of the three-position voltage-regulating relay (raise, lower, and balanced) required for multi-step regulators. The single-step booster uses a simple resonant relay as the voltage-sensitive element. The basis of this relay is a nonlinear circuit consisting of a resistor, a reactor, and a capacitor connected in series with an auxiliary relay coil connected across the capacitor. The

nonlinear characteristics of the circuit permit an accurate and permanent adjustment of the pick-up and drop-out of the auxiliary relay.

Synchronous Condenser With Voltage Regulator (9)

The chief application of this means of regulating the voltage is to situations requiring power-factor correction. Such correction, in the case of transmission systems, may involve under-excited operation of the synchronous condenser. Modern types of generator voltage regulators are available for providing continuous automatic control of the excitation of the condenser throughout its leading and lagging range. Obviously, such equipment is suitable for rapidly correcting deviations from the required voltage level.

Shunt Capacitors Controlled by a Voltage-Regulating Relay (10)

Automatically switched shunt capacitors have found limited application in Europe[8] as a substitute for the voltage-regulator-controlled synchronous condenser where the absence of rotating machinery with the associated maintenance and control problem, as well as the losses involved, have favored this solution. This scheme is in general limited to adjusting the amount of connected capacity in a few steps and because of the duty on the switchgear involved the scheme is not well adapted to rapid and frequent correction of voltage conditions. In case of loss of load, further switching problems arise which have apparently been successfully solved in Europe only because of the longer switching times that are considered satisfactory there as compared with American practice.

The recent introduction in the United States of a low-capacity low-cost equipment to switch shunt capacitors installed on feeder circuits has opened a new field for this method of voltage control.

In some instances the voltage rise imparted to a circuit by a shunt capacitor, installed for power-factor correction, exceeds desirable limits under light load conditions. This objectionable feature can be eliminated by disconnecting all or part of the capacitors with this automatic switch. A conventional voltage-regulating relay controls the switch which has sufficient inherent time delay to prevent unnecessary switching of the capacitors with momentary transient voltage fluctuations.

If more than one step is desired, a corresponding number of these switches, all controlled by the same voltage-regulating relay, can be used. The use of a multistep equipment located at the extremity of a feeder circuit provides an effective means for compensating for more or less voltage drop throughout the entire load cycle.

Shunt Reactors Controlled by a Voltage-Regulating Relay (11)

The use of such reactors has been proposed, especially where the charging current of high-voltage transmission lines would otherwise require the connection of synchronous condensers having excessive lagging capacity. However, this scheme is subject to some of the same disadvantages as the use of shunt capacitors controlled automatically in blocks and has the further disadvantage of being useless if correction of low power factor is required.

Shunt Reactors With Saturating Windings Automatically Controlled (12)

Although not subject to the disadvantage of changing the voltage in large steps as is the case when shunt reactors are switched in and out of circuit, shunt reactors having saturating windings are limited to locations where correction of low power factor will not be required and also cannot be used to correct lighting flicker conditions, since the time constant of the d-c saturating circuit precludes instantaneous response to voltage changes. Furthermore, unless special construction is used, it is not possible to eliminate objectionable harmonics, due to the presence of high saturation in the reactor core, that will introduce new problems from the standpoint of inductive coordination. Most of the special construction features used or proposed to eliminate such harmonics are definitely limited to certain system connections not usually encountered in the United States.

Series Capacitors (13)

When used to correct voltage conditions, it must be realized that at best, series capacitors cannot correct for variations in the supply voltage of the circuit but can only correct for the inductive voltage drop. To be effective at all, the ratio of reactance to resistance in the circuit must be high, and care must be used in their application to circuits to which certain types of load are connected.[9] Series capacitors are relatively expensive because they must be entirely at line potential and also include special protective means for short-circuit conditions on the feeder or transmission circuit to which they are applied. In general, it will not be found advisable to attempt to over-compensate for the reactance drop in an attempt to correct for part of the resistance drop in the circuit. The existence of tapped loads along the feeder will frequently make it inadvisable to consider their application. Although unsuited for correcting light flicker due to sudden loads at high power factor, they offer probably the most effective single corrective means for rapid voltage fluctuation due to low-power-factor load increments.

Series Reactor With Saturating Windings (14)

Although the freedom from moving parts and absence of need for special short-circuit protection for the reactor itself at one time made this device look promising for feeder-regulating purposes, it has not as yet found general application. It necessarily has a bad effect on the circuit power factor, and is too slow in action to mitigate light flicker appreciably.

Summary

As an example of how the commoner types of voltage-regulating equipment may be applied to a power system primarily on the basis of their characteristics, figure 4 has been prepared.

References

1. Regulation Beyond the Distribution Substation, P. E. Benner. AIEE Transactions, volume 54, pages 832–7.

2. Calculation of Alternator Swing Curves, F. R. Longley. AIEE Transactions, volume 49, pages 1129–50.

3. Quick-Response Excitation, W. A. Lewis. *Electric Journal*, volume 31, pages 308–12.

4. First Report of Power System Stability, AIEE Subcommittee on Interconnection and Stability Factors. Electrical Engineering, February 1937, especially pages 270–1.

5. Overvoltage on Transmission Systems Caused by Dropping Load, E. J. Burnham. AIEE Transactions, volume 51, pages 105–12.

6. Parallel Operation of A-C Generators With Individual Voltage Regulator Control, J. W. Dodge and L. W. Thompson. *G. E. Rev.*, March 1936, page 131.

7. Slide Rule Yields Lamp Flicker Data, C. P. Xenis and W. Perine. *Electrical World*, October 23, 1937, page 1375.

8. Starkstromkondensatoren in Einheitsbauweise und ihre Anwendung in Mittel- und Hochstspannungsnetzen, K. Baudisch and W. Rambold. *Siemens Zeitschrift*, September 1937, pages 461–78.

9. Analysis of Series Capacitor Application Problems, J. W. Butler and C. Concordia. Electrical Engineering, August 1937, pages 975–88.

A D-C Transformer

By T. C. LENNOX
ASSOCIATE AIEE

E. V. DeBLIEUX
ASSOCIATE AIEE

THE COMPANY with which the authors are connected undertook the design and construction of a device using a mechanical commutator which would transform direct current from one voltage to another.

The two major commutator problems are current collection and commutation. It is well known that it is difficult to solve these problems especially if certain limits are exceeded. In the case of current collections, the speed of moving contacts cannot be indefinitely increased.

In the case of commutation the chief limitation is in the voltage per bar. Designers of commutator machines have established limits of a few hundred volts in the case of small current and limits of about 60 volts for machines of any considerable output. To obtain practical designs of commutators for high-voltage circuits it is necessary to increase the voltage per bar to very large values, usually approaching the breakdown voltage of the air or other medium surrounding the bar. As sparking may ionize the air and initiate arc-over, it is necessary to have very nearly perfect commutation and current collection.

Accepting this requirement of design, it is necessary to devise circuits which will give very good commutation of current and voltage under all conditions of service. Such circuits may be arranged to rectify or invert alternating or direct current or to transform direct current from one voltage to another. If rectification or inversion is attempted, two great difficulties are encountered. First, that of obtaining perfect synchronization of the commutator with the alternating potential and, second, the balancing of the current and voltages of the a-c system against those of the d-c system. If the currents from any finite number of phases of alternating current are rectified and totaled, the resultant current is pulsating and consequently will not perfectly balance a continuous current.

These difficulties are absent in the case of transformation of direct current, using two commutators carried on one shaft and connected respectively to the primary and secondary of a suitable transformer. Synchronization is perfect and inherent and if the number of commutator bars per circuit is the same on the primary and secondary sides of the apparatus, a true balance of current and voltage is possible. The work described in this paper was based on this type of apparatus.

In the course of the experiments, many types of commutators and circuits were tested, the earlier tests resulted in the arrangement shown in the circuit diagram of figure 1. Typical oscillograms are

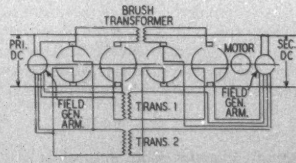


Figure 1. D-c transformer circuit with synchronous excitation and commutation and with brush transformer

shown in figure 2. Figure 3 is a photograph of the test arrangment.

This circuit employs synchronous condensers to supply the transformer excitation and to commutate the load current. This earlier work covered a period from 1924 to 1926. At that time we were not aware of any work having been done with this type of circuit. Subsequently a patent[1] came to our attention. Within the last few years the work of others[2] on this same type of circuit has been published. Since these publications explain the principle of operation we need discuss only the brush transformer which is a novel feature and not included in other circuits.

The most desirable wave shape of transformer voltage, from the standpoint of the commutator, is a trapezoidal shape. This would ordinarily necessitate a special and difficult design of synchronous condenser to supply the excitation, but, by adding the brush transformer to the circuit, a standard sine-wave generator may be used, as the brush transformer absorbs the difference between the supplied and the required voltage wave shapes.

Since the apparatus is essentially a transformer, it was felt that the measure of its success would be its ability to meet the same tests as a normal power transformer which includes short circuit, sudden application and removal of voltage with and without load, double-voltage test, etc.

The apparatus shown in figure 2 was operated at loads up to approximately 30 kw, 1,300 volts for periods up to 12 hours. Nevertheless, it was concluded that this type of apparatus could not be made to successfully withstand the tests specified above for the following reasons:

(1) It is extremely difficult, and one might say practically impossible from a practical and economical standpoint, to design synchronous condensers of any appreciable size that would respond fast enough to prevent flashing over the apparatus on sudden large voltage or current changes.

(2) In the type of commutator (open-circuit type) required, the brush rides alternately on conducting and insulating segments. Because of the difference in the material of the segments, unequal wear results, producing sparking and ultimate failure. Also the insulating segments become dirty and necessitate providing very long creepage paths. To minimize these

Figure 2. Wave forms obtained with circuit of figure 1

troubles, very frequent servicing of the commutator would be required.

(3) The difficulties outlined above and other difficulties, such as minute sparking, that are negligible at small currents and voltages are greatly magnified at higher currents and voltages and cause frequent flashover.

Further experiments to find a more satisfactory circuit resulted finally in the circuit shown in figure 4 and photograph,

Paper number 38-41, recommended by the AIEE committee on electrical machinery and presented at the AIEE North Eastern District Meeting, Lenox, Mass., May 18-20, 1938. Manuscript submitted February 10, 1937; made available for preprinting March 23, 1938.

T. C. LENNOX is an engineer on step voltage regulators for the General Electric Company, Pittsfield, Mass., and E. V. DEBLIEUX is a development engineer for the same company.

1. For all numbered references, see list at end of paper.

figure 5. In this circuit static condensers are substituted for synchronous condensers, the brush transformer is eliminated and the commutator is changed to the type (short circuit) in which the brushes ride solely on conducting segments with an air gap as insulation between the segments.

Most of the subsequent tests were made with the circuit shown in figure 4. A large number of tests were made at loads of 100 to 200 kw, 3,000 volts direct current. Since the only previous disclosure of this apparatus has been by patent,[3] it will be discussed in detail.

Referring to figures 4 and 5, there are seen to be two commutators mounted on a driving shaft with a motor. A minimum of six bars per commutator, connected through suitable slip rings to the primary and secondary windings, respectively, of a three-phase transformer are required. For mechanical reasons, a larger number of commutator bars, which must be a multiple of six, is desirable. The commutators shown in photograph, figure 5, have 18 bars, of which three are connected to each slip ring.

The transformer is of normal construction with reactance and losses such as are acceptable for commercial a-c use. Lower core density than usual was used, for reasons to be explained later. The frequency depends on the rotational speed of the commutator and may consequently be selected to suit the particular design.

Figure 3. Apparatus used for tests of circuit of figure 1

The motor has a suitable regulating device to enable it to maintain constant speed under all conditions.

Voltage Commutation

Three excitation capacitors are connected diametrically on the six-phase primary winding of the transformer. They may equally well be connected to the secondary as the magnetizing ampere-turns may be supplied through either winding.

Assume that the commutators are rotated at constant speed, that d-c voltage is applied to the brushes of the primary commutator and that the three-phase transformer is of core-type construction. The voltage generated in each phase will be of the form shown in figure 6, provided the correct size of excitation capacitors are used and provided the timing of the commutator as determined by brush width, bar width, and slot width is correct.

To explain the generation of the voltage, reference should be made to the simplified diagram of figure 7*a*. As the commutator revolves the two active bars come under the brushes and full d-c voltage is applied to the winding and capacitor. This continues for the period 1-2 in figure 7*b*. The d-c line is then disconnected by the commutator until connected in the opposite direction for the period 3-4.

When the connection is made at 1, sufficicnt current will flow into the capacitor to charge it up to the potential of the d-c lines. At the same time current will begin to flow through the winding and will increase at such a rate as to generate a counter electromotive force in the winding equal to the d-c line voltage in accordance with equation:

$$e = L\frac{di}{dt}$$

When point 2 is reached and the coil and capacitor are disconnected from the line, this current in the coil will be forced to flow through the capacitor. The result is that the capacitor is rapidly discharged and an oscillatory current set up in the loop formed by the coil and capacitor. The resultant oscillatory voltage across the coil and capacitor will have the form shown at E_1 in figure 7*b*. It will oscillate until the commutator reconnects the d-c line at 3, when it will be absorbed by the line, and d-c voltage applied to the coil in the opposite direction.

The frequency and amplitude of the oscillatory voltage are determined by the relative inductance, resistance, and capacitance of the circuit. These factors are under the control of the designer, as are the relative periods of time 1-2 and 2-3. Consequently, by varying these constants, and more particularly, by selecting the correct capacitor for a given transformer, the oscillation may be made to take the form E_2 of figure 7*b*. Here the crest of the first half cycle of the oscillation coincides in time and magnitude with the d-c line voltage which is

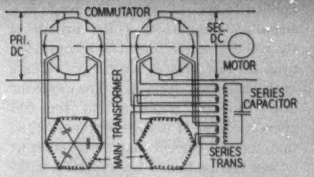


Figure 4. D-c transformer circuit with static-capacitor excitation and commutation

Figure 5. Apparatus used for tests of circuit figure 4

applied to the coil at 3. The result is a smooth commutation of the voltage of the coil during the time it is disconnected from the line, and, an alternating voltage in the coil of the form E_2. The capacitor being directly connected to the coil offers a circuit of negligible reactance, so that the coil current may be diverted at 2 from the d-c line to the capacitor without causing a spark. At 3 the coil and capacitor have a voltage equal to line voltage and are consequently reconnected without sparking.

In the case of the six-phase system the interaction of three phases results in the voltages shown in figure 6. The lower trace of the oscillogram, figure 8, shows such a wave form of voltage.

It will be noted that commutation of the voltage is obtained by matching the frequency of an oscillation with the speed of a commutator. Obviously, in order to maintain this condition the speed of the commutator must remain constant. Moreover the inductance and capacitance of the circuit must also be constant, as otherwise the frequency of oscillation will change. This precludes the use of transformer core densities approaching saturation, as a small change in applied voltage will result in a great change in inductance in such a transformer. The iron should be worked at appreciably lower densities than those customary in power transformers. This necessitates a reasonably high frequency if economical design is to result, and that in turn requires high commutator speeds—this being one of the difficulties of the design of such apparatus. The commutation of rapidly changing voltages offers other problems which will be described later, together with their solution.

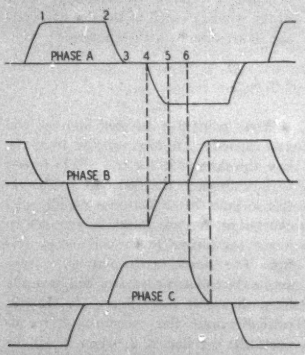


Figure 6. Phase voltages obtained with circuit of figure 4

Load Commutation

Now assume that a load is connected to the secondary terminals of the circuit shown in figure 4. Direct current will flow from the brushes to the load and must pass through the transformer windings. Corresponding currents will flow in the primary windings and will be drawn from the primary d-c line.

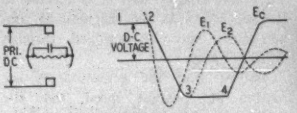


Figure 7a (left). Schematic diagram of excitation of circuit

Figure 7b (right). Wave form of voltages

The wave form of current in the transformer winding will be as shown in figure 9. During the period when the brushes are not short-circuiting any bars, all phases will be in series on each side of the polygon and $\frac{1}{2}$ d-c load current will flow through each of them. This condition exists during period 2-3, figure 9. The currents in the secondary commutator (figure 4) must also pass through the windings of the single-phase series transformer and a corresponding current will be induced in its secondary winding. This current will charge the series capacitor and raise the potential across its terminals. It may be noted that all the currents in the primary windings of the series transformer are not additive, four being in one direction and two reversed, the algebraic sum being effective in inducing current in the secondary.

At time 3, figure 9, the commutator will have moved so that two bars of phase 1 are simultaneously under each brush and both windings of one phase of the transformer are short-circuited. Also, these short circuits each include two windings of the series transformer. The voltage of the charged series capacitor is, therefore, available to circulate current in the loop formed. At the moment the short circuit is caused by the brush, one-half d-c line current is flowing in each winding. The current set up by the capacitor voltage tends to decrease this current. Due to the leakage reactance of the transformer windings in which the current is flowing, the current not only decreases to zero but passes through zero and tends to oscillate at a frequency determined by the constants of the circuit. By suitably designing the commutator and transformers and selecting the correct capacitance, this oscillation is made such as to cause the current, at approximately the crest of the first half wave, to coincide in time with the clearing of the short circuit by the further rotation of the commutator and in value with one-half of the d-c line current. The result is that current is diverted to the d-c line without sparking. The dash curve C_1, shown for phase 2, figure 9 indicates in more detail the nature of this commutation of load current.

Figure 8. Oscillograms of commutation current and phase voltage of circuit of figure 4

The current in the series transformer secondary and in the capacitor is shown in the top trace of figure 9. It is seen to be the algebraic sum of the three-phase currents and to be of triple frequency. The top trace of the oscillogram, figure 8, shows this current.

As in the case of voltage commutation previously described, the success of the scheme depends on the maintenance of a fixed frequency and of fixed constants in the circuit.

The commutating circuit forms a closed loop during the commutating period and commutation proceeds independently of occurrences in other parts of the apparatus, giving a final value of current exactly equal and opposite to the initial value. Consequently, if the d-c line current changes during this period due to changes in load, the final current will not be equal to the new value of the d-c current and arcing at the brushes will occur. This is the primary cause of difficulty in commutating during load transients and short circuits. The means used to mitigate these difficulties will be discussed later.

The charging of the capacitor during the period between commutations is necessary to store up sufficient energy to supply the resistance losses of the circuit during commutation. Too short a charging period for the capacitor will result in the current failing to reach the correct

value at the correct time, regardless of the value of the capacitance provided.

As a result and as may be seen from C_1, figure 9, commutation of the current begins at a definite rate, as indicated by a tangent to the oscillation at this point, and an appreciable voltage exists between the brush and each approaching bar.

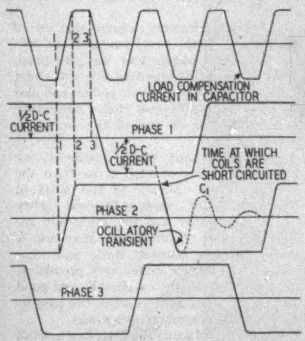


Figure 9. Current wave shapes obtained with circuit of figure 4

The result is a tendency to burn the leading edges of both due to the sudden rush of current. This was found to be a real difficulty in the operation of the apparatus.

Commutator Design

The design of commutators intended to operate with thousands of volts between bars takes us into somewhat unexplored fields of engineering. The conventional commutator teaches little except that true roundness, and great strength and rigidity to maintain it, are of great importance. When working with high-voltage commutators it is soon found that this quality is of even greater importance and must in no way be sacrificed to insulation and other factors.

A different type of commutator from figure 5 is shown in figure 10. The largest commutator tested is shown in figure 11. Due to difficulties resulting from thermal expansion of the bars, this commutator did not operate as satisfactorily as hoped. It is of interest, however, that this commutator, together with the necessary transformers, capacitors and other parts, was used for many months as a source of 3,000 volts direct current for experiments on other models. When run under load for some hours it was observed that the leading edges of the bars and brushes would blacken no matter how much care was taken to keep the commutator smooth and round. This blackening of bars and brushes on the leading edges was due to the abrupt beginning of commutation, as previously described. The voltage of the charged series condenser causes current to flow

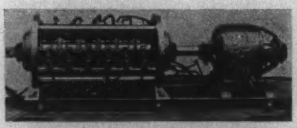


Figure 10. 100-kw 3,000-volt commutator

from brush to approaching bar at a rapidly increasing rate as soon as contact is established at any point. The result is a slight spark which eats away the copper and carbon.

The commutator shown in figure 5, which was built for 25 kw, 3,000 volts was by far the most successful from the mechanical standpoint. The bars were encased in mica and clamped into deep grooves in a metal wheel. Being clamped at one point only, they could expand freely endways when heated in operation. On the heavy steel shaft is mounted a machine-steel disk. In the periphery of the disk are milled "V" shaped slots. The wedge shaped commutator bars are moulded into mica and set into these slots. The bars project from the slots on both sides of the disk. On one side were attached the slip rings and on the other the molybdenum commutator segments. Thus the whole structure was carried on the one steel disk. To obtain the necessary strength and rigidity a heavy steel retaining ring was placed over the disk and bars, and steel fillers inserted between the ring and the mica insulation on the bars. These fillers were pressed down onto the bars by set screws threaded through the ring.

The timing of the commutator is determined by the relative width of bar, of slot, and of brush. However, these factors cannot be varied outside of certain limits. For instance, a brush too narrow will not ride smoothly over the bars and slots, and slots too wide in proportion to the bar width will, similarly, lead to uneven action. As the timing is determined in part by the width of brush, it is essential that the latter be "worn in" over its whole surface and be free from broken edges.

The most unusual feature of the structure is the molybdenum segment on each bar. These were used to avoid the blackening of the leading edges of the bars. This blackening results from the voltage of commutation between brush and bar and the consequent immediate rise of current at contact. The minute spark attending this condition evidently vaporizes copper and thereby makes pittings in it. The high melting point of molybdenum, together with its slowness to oxidize prevent this to an extent within the ability of the brush to keep it polished.

However, the leading edge of carbon or graphite brushes would still blacken and get rough. In spite of the high melting and evaporating points of carbon, its poor heat conductivity, together with its readiness to oxidize, evidently caused this result. Finally a few layers of molybdenum gauze were placed against both leading and trailing faces of the brush and cemented inside a thin casing of horn fiber. The graphitized carbon of the brush was found to lubricate the molybdenum gauze sufficiently to avoid severe wear of the commutator, while the gauze resisted the destructive action of the current. With this arrangement and carefully worn in brushes many tests were run without showing any apparent deterioration of brush or bar.

Commutation With Varying Supply Voltage

Earlier tests had indicated that voltage could be thrown directly onto a "dead" machine provided it was running at normal speed, but this had never been

Figure 11. 300-kw 3,000-volt commutator

confirmed by applying as much as 3,000 volts with a large generating capacity back of it.

The principal difficulty to be anticipated here is that of commutating the transient magnetizing current that flows for a few cycles when a transformer is thrown onto the line. This transient current reaches very large values if the flux density in the iron is normally high. The low densities required for the d-c

transformer, as already mentioned, bring this current down to values of the order of twice the normal magnetizing current, although the very worst condition, which is that of strong residual flux in the core and switching at the zero point of the wave, will result in somewhat more than this.

An arrangement of reactor, capacitor, and resistor, connected between the line and the commutator, when correctly proportioned, gave perfect results, no arc-overs occurring during a large number of voltage applications. If load were connected to the equipment, however, the reactor core would be saturated by the d-c load current. To avoid this it was provided with two windings having the same ratio of turns as the d-c transformer, and connected in both primary and secondary d-c circuits, but in opposite directions so that the load currents opposed, and hence had no effect on the core. The d-c energizing currents flowing from either or both d-c lines do not oppose and hence encounter the full inductance of the reactor, and are effective to reduce transient voltages on the commutators. A capacitor and resistor may be connected between the reactor and commutator on the primary side only, or on both primary and secondary if the equipment is to be energized from either side. The effect is to apply the voltage gradually during the first few cycles and so reduce the transient magnetizing currents.

Commutation With Varying Load Current

By having a suitable reactor connected in series with the equipment, variations in load current will set up counter electromotive forces in the reactor which oppose the change in current and cushion the effect on the commutators. By such means the equipment is made to function satisfactorily with a varying load.

To avoid damage from flashover, the equipment may be protected with high-speed circuit breakers. There being no mechanically stored energy in the apparatus which could flow into a flashover, such protection will be much more effective than in the case of machinery with a rotating armature or field structure.

Conclusions

It is felt that the circuit constants and difficulties in mechanical construction have been fairly well explored in connection with this investigation and the data obtained should be of value in connection with new projects. The growing need of high- and low-voltage direct current in many fields of electrical engineering should result in additional applications being undertaken.

References

1. United States patent 1,206,662.

2. (*a*). Synchronous Mechanical Rectifier-Inverter, **S. S. Seyfert**, AIEE Transactions, volume 52, June 1933, pages 397–407. Also AIEE *Journal*, May 1936, pages 548–53.

(*b*). New Systems for Producing Electromagnetically High Voltage Direct Current, **E. Alm**. *Proc.* Int. Conference on Large H. T. Systems, 1935, volume 3, paper number 347.

3. United States patent 1,659,110.

Discussion

J. J. Linebaugh (General Electric Company, Schenectady, N. Y.): [**Editor's Note:** This discussion covers also "New Types of D-C Transformers," C. C. Herskind, Electrical Engineering (AIEE Transactions), volume 56, November 1937, pages 1372–8.] It is very interesting to have the two papers describing two such radically different ways of accomplishing d-c transformation for consideration at the same time.

Engineers have long dreamed of a simple way to transform direct current from one voltage to another voltage similar to the well-known a-c transformer and numerous attempts have been made to solve this difficult problem. Most attempts have been along the lines of a commutator driven by a synchronous motor of some kind connected to operate as an inverter and as a rectifier.

The two papers on this subject—one using straight mechanical means and the other mercury-arc rectifier vacuum tubes to build up a unit which would accomplish the desired conversion—outline a very serious attempt to solve this problem so that a commercial d-c transformer would be available.

Messrs. Lenox and DeBlieux outline the line of attack followed, frank discussion of difficulties encountered, and results obtained. It is the most ambitious attempt known to the writer to solve this problem and should be of interest to many engineers and especially to any one working on the development of such a transformer in the future.

It will be of interest to know that one of the reasons for the development of the 300-kw 3,000-volt transformer was the possibility of operating standard 600-volt street cars on a standard 600-volt system and also on a 2,400- or 3,000-volt trolley system by simply throwing on and off the d-c transformer.

Several locations were considered, one being the routing of such a car from the hotel in Butte, Mont., to the hotel in Anaconda, Mont., using a 600-volt trolley in the two towns and the 2,400-volt 28-mile main line of the Butte, Anaconda & Pacific Railway between Butte and Anaconda. The scheme looked very promising, but unfortunately the automobile and good roads came along and absorbed the passenger business between the two towns.

Mr. M. A. Edwards has described a small inverter built along the lines of the unit described by Messrs. Lennox and DeBlieux using improvements and material made available since that time. This application has real merit and, if the demand for a d-c transformer becomes great enough undoubtedly the authors have opened the way to the development of a successful transformer of the nontube type.

Mr. Herskind, on the other hand, describes connections, circuits, characteristics, etc., using mercury-arc rectifier tubes to take care of commutation difficulties and sequence of circuits instead of a mechanical commutator. The circuits tried out, giving either constant current or constant voltage output, open up many possibilities for future application.

While the units under test were not as large as the 300-kw d-c transformer, they were large enough to demonstrate the practicability of such a unit.

The size of this type of d-c transformer is dependent on capacity and reliability of mercury-arc rectifier tubes.

Perhaps the d-c transformer of the future will be a combination of the two lines of attack covered by these interesting papers.

It is believed a d-c transformer can be made available for commercial use if demand is great enough to warrant the cost of development.

THE CAREFUL INVESTOR JUDGES A SECURITY

BY THE HISTORY OF ITS PERFORMANCE

KERITE

IN THREE-QUARTERS OF A CENTURY OF

CONTINUOUS PRODUCTION HAS ESTABLISHED

A RECORD OF PERFORMANCE

THAT IS UNEQUALLED IN THE HISTORY OF

INSULATED WIRES AND CABLES

THE KERITE INSULATED WIRE & CABLE COMPANY INC

NEW YORK CHICAGO SAN FRANCISCO

Industrial Notes

Electrical Equipment Exports Decline.—United States exports of electrical equipment during June were valued at $9,111,494, a decrease of 3.1 per cent from the month of May and 9.1 per cent from the corresponding month last year, according to the electrical division, Bureau of Foreign and Domestic Commerce. Although 1938 promises to be a comparatively good year for electrical exports, to date it has not kept pace with the excellent showing made in 1937. Electrical equipment exports for the first six months of this year were valued at $56,451,131 against $60,012,750 for the corresponding period of 1937.

Building Construction News.—The building industry, paced by residential construction, continued in July to compare favorably with past records, according to compilations of the F. W. Dodge Corporation, New York. The valuation of all residential contracts awarded for July 1938 was $87,978,000, which was $6,932,000 ahead of July of last year. The entire gain is in one- and two-family houses; relatively few of the large low-rental projects and public housing projects have progressed to the work stage. Contracts awarded for non-residential building in July showed a slightly more than seasonal decline of 11 per cent from June. Heavy engineering construction, comprising public works and utilities, has not yet begun to show the effects of the Federal spending program. The value of all contracts awarded, building and heavy engineering combined, for July, aggregated $239,799,000. The seven months' accumulative of $1,534,071,000 while 15 per cent below the same period in 1937, is substantially ahead of any other year since 1931.

Record Order for Street Cars.—The City of Toronto, Canada, has placed an order for 140 P.C.C. cars, the largest expenditure to be made for street railway cars in ten years, according to the American Transit Association. The amount involved is $3,000,000. Contract for the new cars was awarded to the Canadian Car and Foundry Co., of Montreal, which has secured rights to manufacture them in Canada. Steel structures will be built in the shops of the St. Louis Car Co., and exported to Canada. The 560 traction motors and auxiliary electrical equipment will be manufactured by the Canadian Westinghouse Company at Hamilton, Ont.

Instrument Prize Contest.—An instrumentation contest with a first prize of $200 is announced by the industrial instrument section of Scientific Apparatus Makers of America. Twelve prizes in all, totaling $500, will be awarded. The contest is open to any engineer or operating man, not employed by an instrument manufacturer. Each contestant is to write about an unusual application of a standard instrument or control device, telling briefly what conditions or need impelled the application. The contest will be judged by the following jury of award: Dr. Lyman J. Briggs, chairman, (Director, National Bureau of Standards,) M. F. Behar, W. E. Forsythe, John J. Grebe, R. J. S. Pigott and P. T. Sprague. The contest closes November 15, 1938 and the judging will be held during the week of December 5. Copies of the contest rules and official entry form can be obtained from Scientific Apparatus Makers of America, 20 No. Wacker Drive, Chicago, Ill.

Pittsburgh Office for Roebling.—A branch office and warehouse has been established by John A. Roebling's Sons Co., at 855 North Ave., W., Pittsburgh. A complete line of insulated wires and cables and wire rope will be stocked. The Frick-Reid Supply Corporation no longer distributes Roebling products in Pittsburgh.

G-E Appointments.—A. E. Newman has been appointed manager of General Electric wiring materials sales section, Bridgeport, Conn. F. A. Parnell has been appointed sales manager of conduit; J. F. Farnum sales manager of wire and cable. L. F. Giblin is now supervisor of distribution development, wiring materials section, and J. P. McIlhenny sales manager of the wiring materials field organization.

Trade Literature

Motors.—Bulletin M-60, 2 pp. Describes shaded pole induction motors, type YAr, in three frame sizes, with 4- to 20-watts output. Barber-Colman Co., Rockford, Ill.

Capacitors.—Bulletin GEA 2561B, 12 pp. Describes Pyranol distribution capacitors, individual pole type units, class ID, for 208- to 13,200-volt circuits. General Electric Co., Schenectady, N. Y.

Washers.—Stock List 55-B. Lists thousands of washer specifications in various materials, including steel, brass, copper, aluminum, fibre, etc., available for immediate shipment. Wrought Washer Mfg. Co., 2100 S. Bay St., Milwaukee, Wis.

Propeller Fan Blades.—Bulletin 123738, 12 pp. Describes standard, deluxe and air circulator fan blades. Specifications and available sizes are shown in table form, and graphs give NEMA code recordings on air delivery and power consumption. The Torrington Mfg. Co., Torrington, Conn.

Relays.—Bulletin GEA 2827, 12 pp. Describes polyphase power-directional relays, high speed, induction-cup type, for protection of transmission lines. These relays utilize the induction-cylinder principle of design, which provides a steady high torque on a low-inertia element. General Electric Co., Schenectady, N. Y.

Instruments.—Catalog 1060D, 64 pp. Describes indicating, recording and controlling instruments for temperature and pressure. Includes a new line of recording thermometers and pressure gages with 10-inch and 12-inch charts. C. J. Tagliabue Mfg. Co., Park Ave., Brooklyn, N. Y.

Welding Electrodes.—Bulletin R-5, 28 pp. Describes "Smootharc" welding electrodes, available in many types. The bulletin includes spark tests, procedure sheets, welding charts and other informative suggestions. Harnischfeger Corp., Milwaukee, Wis.

Circuit Breakers.—Desc. Data 33-675, 12 pp. Describes type "U" De-ion air circuit breakers designed for indoor service, applicable to standard voltage ratings of 2,500 to 15,000. Furnished in standard current ratings of 2,000 amperes and available in one, two, three and four pole arrangements. Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

Relays.—Bulletin 3. Describes new types 3-A and 3-B relays, particularly adaptable to supervisory circuits and coupling to photoelectric systems. Although rated at 12 milliwatts direct current, the type 3-A relay will handle moderate loads with as little as 6 milliwatts input. The input rating of the type 3-B relay is only 4 milliwatts direct current. Sigma Instruments, Inc., Belmont, Mass.

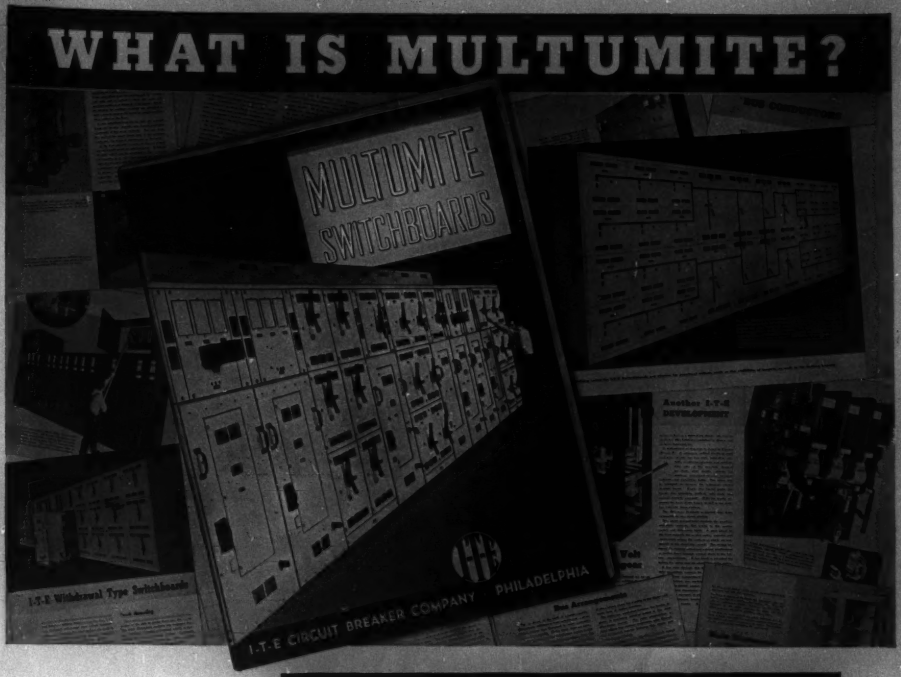
Copperweld Telephone Lines.—Bulletin E. D. 1683, 8 pp. Describes the application of Copperweld wires to overhead communication circuits. Includes tables on the mechanical and electrical characteristics of these conductors supplemented with data on safety, reliability of service, speech transmission characteristics, economy and line construction practise. Copperweld Steel Co., Glassport, Pa.

Substation Unit.—Bulletin GEA 2840, 62 pp. Describes the single-circuit substation unit, a standard three-phase transformer arranged for changing taps under load, and equipped with lightning arresters and a standard low-voltage circuit breaker with its control relays and potential and current transformers. The complete equipment is manufactured and assembled as a unit. General Electric Co., Schenectady, N. Y.

Locating Cable Faults.—Handbook E-53-441, 52 pp., "Notes on Fault Location in Cables." Describes procedure in locating cable faults in power or communication transmission. Profusely illustrated with diagrams; explains methods for identifying defective wires in a cable, for measuring conductor resistance, for locating grounds and crosses by Murray and Varley Loop tests and for locating open circuits by capacitance tests. Leeds & Northrup Co., 4962 Stenton Ave., Philadelphia, Pa.

Electrical Features of New Tunnels. Bulletin 738, 12 pp. The lighting and ventilating systems and electrical apparatus used in the operation of the Lincoln Tunnels under the Hudson River between New Jersey and midtown New York City are described and illustrated in this bulletin by S. E. Schultz, electrical engineer, Port of New York Authority. Construction features of the tunnels are outlined. I-T-E Circuit Breaker Co., 19th & Hamilton Sts., Philadelphia, Pa.

WHAT IS MULTUMITE?



MULTUMITES are switchboards designed by I-T-E, embodying latest developments in air-immersed circuit breakers and steel enclosures.

To provide a clear description of modern MULTUMITE switchboards, a new book has been prepared.

Photographs, drawings and text are arranged to furnish a useful outline of modern practice, covering circuit breakers, bus structures and enclosures together with protective and control features.

A copy—40 pages—will be mailed to responsible parties interested in electrical protection. Your position and name of your organization should accompany your request.

I-T-E
50TH YEAR

REPRESENTATIVES IN PRINCIPAL CITIES

I·T·E CIRCUIT BREAKER CO., PHILADELPHIA, PA.

From
FOUNDATION
to
FLAGPOLE

...But WIRE IS ONLY AS GOOD AS ITS INSULATION

United States Rubber Company

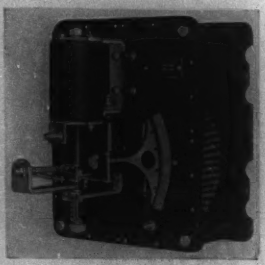
United States Rubber Products, Inc., 1790 Broadway, New York, N. Y.

MANUFACTURERS OF ELECTRICAL WIRES AND CABLES

LINEMEN'S BLANKETS · SPLICING COMPOUND · TAPE · SWITCHBOARD MATTING

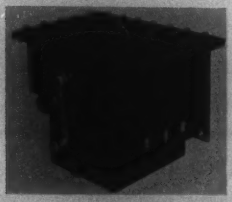
New Products

Rocking Contact Voltage Regulator.—A new, small, inexpensive "rocking contact" type voltage regulator, known as type V-O, designed for automatic voltage control of small a-c and d-c generators, has been developed by the switchgear division, Allis-Chalmers Mfg. Co., Milwaukee, Wis. This regulator consists of a sensitive solenoid actuated plunger which acts upon a main shaft, rocking a special carbon rimmed contact sector over the inner surface of a



commutator, the segments of which are connected permanently to the regulating resistance. There are no vibrating contacts, tubes or other parts requiring replacement or readjustment at frequent intervals. A metal enclosing case excludes dust and other foreign matter, thereby reducing maintenance. Only two simple adjustments are made at the time of installation, since all major adjustments are made at the factory. This proven design of regulator was heretofore available only in the larger rocking-contact principle regulators.

Oil Switch.—In this type "K" subway oil switch with one piece tank, 3-pole, 7500-volt, 200- and 400-ampere, developed by the G & W Electric Specialty Co., Inc., 7780 Dante Ave., Chicago, Ill., a new and novel feature is the incorporation of a clip on the



position indicator plate and a projection on the operating handle that prevents removal of the handle except when the switch is in the open position. Only one handle is provided when two switches are used in a manhole for a double feed, and the interlocking device prevents closing one switch unless the other switch is open.

Combination Meter and Time Switch.—An accurate meter and an improved Telechron-motored time-switch register are combined

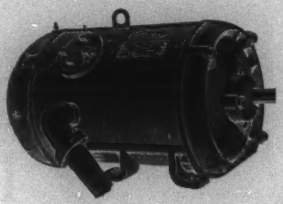
in the new type IR-30, a single unit introduced by the General Electric Co., Schenectady, N. Y. Savings in space, installation and maintenance costs are among the advantages of the single-unit construction. Wide-limit accuracy is assured by incorporation, in the unit, of the established G-E type I-30 watthour meter, which is suited for both large and small single-phase loads. The meter is available in all ratings, with any one of three registers: single dial, with contacts; double dial with contacts; and double dial without contacts, for front connection or for socket mounting.

Radio-Interference-Free Insulators.—A new glaze and simplified processing method is

being installed in the Westinghouse Electric & Mfg. Company's two porcelain plants for making all insulators free from radio interference, at the same price as now paid for ordinary insulators. Research studies have shown that the radio disturbance caused by line insulators of all sizes is due to minute arcs created at the point of contact of conductor and tie wire with the insulator by the normal flow of insulator charging current. While the flow of charging current is inherent in any insulator, it was discovered that the arcing could be eliminated by proper distribution of voltage stress and the introduction of the charging current into the insulator without forming corona. Having found the cause of interference, Westinghouse developed a copper-oxide glaze as an integral part of the insulator as early as 1930.

Generator Controller.—The Columbia Electric Mfg. Co., 4519 Hamilton Ave., Cleveland, O., has recently developed a new type of controller for use with low voltage, high amperage generators where a very close control of the voltage is required. Particularly for laboratory use, it replaces the standard field rheostat and separate exciter. For example, on a 6-volt generator where it is frequently required to use voltages between 0 and 6 volts, this controller will enable the operator to set the voltage at any point within 0.1 volt.

Explosion-Proof Motor.—A complete new line of d-c explosion-proof motors has been announced by The Louis Allis Company, Milwaukee, Wis. According to the manufacturer, the first fan-cooled, explosion-proof motor was originated, developed and patented by this company. One of the



outstanding features of these motors is their small compact overall dimensions which make them interchangeable with a-c and d-c NEMA frame sizes with reference to NEMA dimensions D and shaft sizes; especially important is their unusually low overall height, which adapts them particularly to use in low overhead mines. The motors have been inspected and tested by the Bureau of Mines Laboratory and approved by Underwriters' Laboratories.

Explosion-Proof Rheostat Enclosure.—The Ward Leonard Electric Co., Mount Vernon, N. Y., has developed a new explosion-proof enclosure for vitrohm pressed steel rheostats which meets the requirements of class 1, group D Hazardous Locations. They are of the air break type, for installation in oil refineries, filling stations, distilleries, etc., where

explosive gases are present. All enclosures are of cast iron. A pad tapped for $\frac{1}{2}$-inch pipe for the entrance of wires is provided on the bottom of the case. They accommodate 8-, 13- and $15\frac{1}{2}$-inch diameter Bulletin 60 Vitrohm Pressed Steel Rheostats and are regularly furnished for front of board mounting, but can be arranged for use with manual drive accessories.

MEASURE—INDUCTANCE • RESISTANCE • CAPACITANCE

• • • **ALWAYS READY TO**

THIS universal, self-contained, direct-reading bridge is portable, self-contained and ready to operate at any time. It has proven to be an indispensable tool in hundreds of laboratories where resistance, inductance or capacitance have to be made quickly.

The *direct-reading* ranges of the General Radio Type 650-A Impedance Bridge are:

RESISTANCE: 0.001 ohm to 1 megohm
INDUCTANCE: 1 microhenry to 100 henries
CAPACITANCE: 1 micromicrofarad to 100 microfarads

The bridge contains a 1,000 cycle a-c power source and four dry-cells for both a-c and d-c measurements.

Price, complete except for dry-cells and head telephones: $175.00

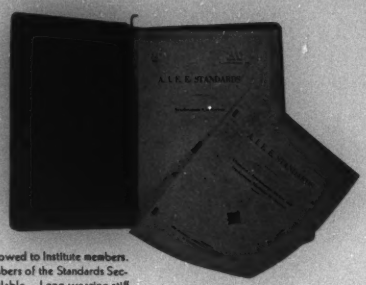
• ***WRITE FOR BULLETIN 305***

Address: 30 State Street, Cambridge, Massachusetts
Or BRANCH OFFICES in New York and Los Angeles

GENERAL RADIO COMPANY

A.I.E.E. STANDARDS

THE Standards of the American Institute of Electrical Engineers now comprise forty-six sections on electrical machinery and apparatus. They are chiefly devoted to defining terms, conditions, and limits which characterize behavior, with special reference to acceptance tests, and many of them are recognized officially as American Standards.



The Standards available are listed below, together with prices. A discount of 50% is allowed to Institute members. Such discount is not applicable on extra copies unless ordered for other members. Numbers of the Standards Sections should be given when ordering. A binder (illustrated above) for standards is available. Long wearing stiff covers, resembling leather, lettered in gold. Price $1.75 net.

(Figures in Parentheses Give Dates of Latest Editions)

No. 1	General Principles Upon Which Temperature Limits Are Based in the Rating of Electrical Machinery (4-25)	$0.20
4	Measurement of Test Voltage in Dielectric Tests (5-28)	.30
*C50	Rotating Electrical Machinery, Supersedes Nos. 5, 7, 8, 9 and 10 (4-36)	1.30
**11	Railway Motors (4-37)	.50
*12	Constant Current Transformers (1-34)	.30
13	Transformers, Induction Regulators and Reactors (5-30)	.40
*14	Instrument Transformers (3-25)	.30
*15	Industrial Control Apparatus (5-28)	.40
*16	Railway Control Apparatus (1-33)	.40
*17f	Mathematical Symbols (2-28)	.30
*17g1	Letter Symbols for Electrical Quantities (11-28)	.20
**17g2	Graphical Symbols for Electric Power and Wiring (1-34)	.20
**17g3	Graphical Symbols for Radio (1-34)	.20
**17g5	Graphical Symbols for Electric Traction Including Railway Signaling (1-34)	.40
**17g6	Graphical Symbols for Telephone and Telegraph Use (3-29)	.20
*18	Capacitors (6-34)	.20
19	**Oil Circuit Breakers (3-38) (NEW)**	**.40**
20	Air Circuit Breakers (5-30)	.30
22	Disconnecting and Horn Gap Switches (7-25)	.30
*C37.1(23)	**Relays Associated with Power Switchgear (1937) (NEW)**	**.40**
*C37.2(26)	**Automatic Stations (1937) (NEW)**	**.40**
27	Switchboards and Switching Equipment for Power and Light (10-30)	.30
*28	Lightning Arresters (3-36)	.30
*30	Wires and Cables (4-37)	.40
*C39.1(33)	**Electrical Indicating Instruments (7-38) (NEW)**	**.40**
*36	Storage Batteries (2-28)	.20
*38	Electric Arc Welding Apparatus (1-34)	.40
*39	Electric Resistance Welding Apparatus (1-34)	.30
*41	Insulators (3-30)	.30
**42	Symbols for Electrical Equipment of Buildings (12-23)	.20
*46	Hard Drawn Aluminum Conductors (6-27)	.20
*60	Specifications for Tinned Soft or Annealed Copper Wire. (See No. 61 for price.)	
*61	Specifications for Soft or Annealed Copper Wire. (Nos. 60 and 61 published as one pamphlet) (9-28)	.30
**C8.4	Specifications for 30 Per Cent Rubber Insulation for Wire and Cable for General Purposes (1936)	.20
*C8.5	Specifications for Cotton Covered Round Copper Magnet Wire. (See C8.7 for price.)	
*C8.6	Specifications for Silk Covered Round Copper Magnet Wire. (See C8.7 for price.)	
*C8.7	Specifications for Enameled Round Copper Magnet Wire. (C8.5, 8.6 and 8.7 published as one pamphlet) (1936)	.30
**C8.11	Code Rubber Insulation for Wire and Cable for General Purposes (1936)	.20
*C8.12	Cotton Braid for Insulated Wire and Cable for General Purposes (1935)	.20
**C8.16	Tree Wire Coverings (1936)	.20
**C8.17	Class OA 30 Per Cent Rubber Insulation for Wire and Cable for General Purposes (1936)	.20
**C8.18	Weather Resistant Wire and Cable URC Type (1936)	.20
**72	Specifications for Weatherproof Wires and Cables. (See No. 73 for price.)	
**73	Specifications for Heat-Resisting Wires and Cables. (Nos. 72 and 73 published as one pamphlet) (9-32)	.20
100	Recommendations for the Operation of Transformers (6-30)	.20
500	Test Code for Polyphase Induction Machines (8-37)	.50
	Total Cost of Complete Set	$13.30

* *Approved as American Standard.*

** *Approved as American Tentative Standard.*

SECTIONS IN PREPARATION

Six such sections are now available in report form for purpose of criticism, and copies will be sent without charge upon request. These sections are as follows:

No. 6	Mercury Arc Rectifiers.	40	Electrical Recording Instruments.
25	Fuses Above 600 Volts.	—	Test Code for Transformers.
501	Test Code for D-C Machines.	—	Test Code for Synchronous Machines.

American Institute of Electrical Engineers

33 West 39th Street New York

PROGRESS...
WITH A PURPOSE

Deltabeston Conductors Built to Answer Your Requirements

There is a Deltabeston Wire and Cable for every application. Each has been built to exacting standards. Each is ready to answer your demands.

From the smallest Magnet Wire to the largest Power Cable, Deltabeston means dependability. It means a background of sound engineering — careful workmanship. It means a desire to build the best wire and cable possible — and doing it!

Constant engineering research has done a lot for Deltabeston dependability. It has brought about Purified Asbestos insulation, through a process that removes harmful impurities from the asbestos. It has perfected a method of felting the insulation, so that cracks and breaks are eliminated.

Next time you specify wire and cable, specify Deltabeston. *It will pay its way in extra service.* For complete information write to Section Y-8189, Appliance and Merchandise Department, General Electric Company, Bridgeport, Connecticut. Deltabeston Wires and Cables are distributed by General Electric Merchandise Distributors and Graybar Electric Company.

PURIFIED ASBESTOS INSULATION FOR HIGHER DIELECTRIC STRENGTH
COMPLETE RESISTANCE TO HEAT, MOISTURE AND OIL

GENERAL ELECTRIC

NEW MODEL VOLTROL!

. . . FOR PANEL MOUNTING

● No laboratory is *complete* without a means of stepless voltage control such as provided by the Acme Voltrol. Manually operated, the Acme Voltrol provides stepless adjustment of A. C. voltage from 0 to 135 volts. For production line voltage tests this new model is ideal. Put voltage control on all test boards and learn *all* the operating characteristics of your product under all voltage conditions. This new panel mounting model is priced lower than ever. Write for catalog.

Inquiries invited from manufacturers who use small, special characteristic transformers in quantity.

THE ACME ELECTRIC & MFG. CO.
22 WATER STREET ◆ CUBA, NEW YORK

Acme Electric

Engineering Societies Library

A reference library for engineers—contains 150,000 volumes—receives over 1,300 technical journals and periodicals on all branches of engineering.

Searches are made upon engineering subjects, translations from foreign publications, photostats made, etc.

Books may be borrowed by members of the AIEE. For information address, The Engineering Societies Library, 33 West 39th St., New York.

At Your Service

40 TYPES OF MEYLAN STOPWATCHES

A watch for every purpose

Let us send folder No. 9E fully illustrating and describing some 40 types of stopwatches. No salesmen will call.

REPAIR SERVICE

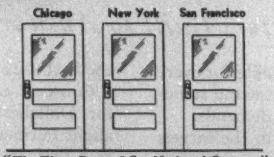
for all kinds of plain and complicated stopwatches. Send to us for estimates; no charge, no obligation.

A. R. & J. E. MEYLAN
"Specialists in timing instruments"
268 West 40th St., New York City

THE THREE DOORS—*The Answer To Your Employment Problem*

To Those Who Employ

The facilities of this service are at your command without cost or obligation. Only qualified applicants are referred to you and everything is done for you to conserve your time, effort and expense.



"The Three Doors Offer National Coverage"

To Those Who Seek Employment

Register with the service immediately. Do not put it off until tomorrow. Employers seeking high grade men now naturally look to their Societies for such men—you surely do not wish to pass that opportunity you have been looking for.

In order to more effectively serve the 75,000 members (approximately) of the Engineering Societies, the Four Founder Engineering Societies in cooperation with a number of engineering organizations have maintained for the past twenty years a nation wide employment service. More than 50,000 opportunities have been presented to our employment directors, who have diligently and efficiently endeavored to find the "right" man for each request.

Men are registered with this service from practically every State in the Union—employers do not have to take the "best they can get" from a limited local market. Make known your requirements to any one of the three offices and your request will receive immediate and careful attention.

ENGINEERING SOCIETIES EMPLOYMENT SERVICE

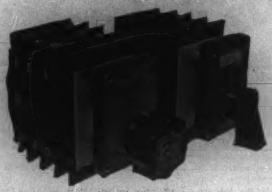
CHICAGO: 211 W. Wacker Drive NEW YORK: 29 West 39th Street SAN FRANCISCO: 57 Post Street

Maintained for Engineers by the Engineering Profession

The National Clearing House for Engineers

A Non-profit Activity of the Founder Engineering Societies for the Benefit of the Profession

ROLLER-SMITH announces



The NEW
Type R-2
INSTRUMENT
and
CONTROL
SWITCHES

Type R-2 switches supersede the dependable Type R line successfully used on thousands of panels and switchboards.

The outstanding improvements in the new model switch are as follows:

1. Occupies less depth behind board.
2. Bakelite barriers between all poles.
3. Bakelite barriers between all terminals.
4. Quick make and break contacts available.
5. Simple unit construction permits almost any number of stages.
6. Sliding side plates instantly removable for inspection of contact parts.
7. Special switches can be assembled on very short notice.

Send for new Catalog AE-9 which gives complete description, connections and prices.

ROLLER-SMITH COMPANY
Electrical Measuring and Protective Apparatus

MAIN OFFICE
12 Park Place, New York

WORKS
Bethlehem, Pa.

Sales Agents in Principal Cities in U. S. A. and Canada.

LOCKHEED PLANE OHMITE-EQUIPPED

Hughes' dash around the world in his LOCKHEED Plane adds another "case history" to the service-record of Ohmite Vitreous-Enameled Rheostats and Resistors. Their ability to withstand overloads and abuse, shock and vibration, heat and humidity, has made them standard equipment on such major airways as Pan-American, United Air Lines, and others, both here and abroad—as well as in the general manufacturing and industrial fields. Send for New Catalog 17 now—or let Ohmite work out your control-by-resistance problem.

OHMITE MANUFACTURING CO.
4842 W. Flournoy Ave. Chicago, U. S. A.

OHMITE ★ Rheostats Resistors Tap Switches ★

CAPACITORS of ALL types

Electrolytic capacitors for intermittent starting service.

★

Oil-filled capacitors for continuous service.

★

Widest choice of containers, mountings, terminals, etc.

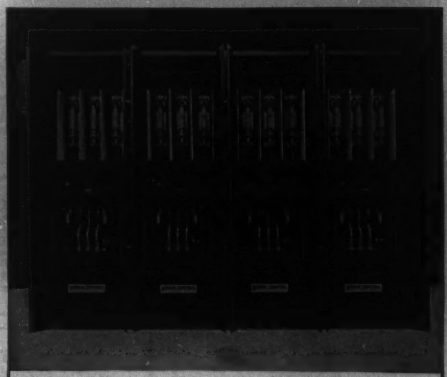
★

Largest line of standard units listed and stocked. Special types to order.

★

● Regardless of what your motor-starting or other capacitor requirements may be, AEROVOX has the engineering experience and production capacity to serve you well. ● Submit that problem for engineering aid, samples, quotations. ● Data on request.

AEROVOX CORPORATION



A bank of completely steel enclosed, 2300 volt oil immersed starting units complete with fused disconnect switches and bus structure.

ROWAN CONTROL
THE ROWAN CONTROLLER CO., BALTIMORE, MD.

Professional Engineering Directory

For Consultants in Engineering and Allied Sciences

BLACK & VEATCH
Consulting Engineers
Water, Steam and Electric Power Investigations, Design, Supervision of Construction, Valuation and Tests
4706 Broadway KANSAS CITY, MO.

GEORGE T. SOUTHGATE
ELECTRICAL AND THERMAL ENGINEER
Consultant in Apparatus, Process and Patent Matters
Office and Laboratory
114 East 32nd Street NEW YORK

FRANK F. FOWLE & CO.
Electrical and Mechanical Engineers
35 East Wacker Drive CHICAGO

HOWARD S. WARREN
Consulting Electrical Engineer
420 Lexington Ave. NEW YORK

JACKSON & MORELAND
ENGINEERS
Public Utilities—Industrials
Railroad Electrification
Designs and Supervision—Valuations
Economic and Operating Reports
BOSTON NEW YORK

A card here will keep your name and specialized service constantly before 21,000 readers of this publication.

Z. H. POLACHEK
Reg. Patent Attorney
Professional Engineer
PATENT—TRADE MARK SPECIALIST
Individual or Yearly Basis
1234 Broadway Phone
(At 31 St) NEW YORK Longacre 5-3088

THE J. G. WHITE ENGINEERING CORPORATION
Engineers—Constructors
Oil Refineries and Pipe Lines, Steam and Water Power Plants, Transmission Systems, Hotels, Apartments, Offices and Industrial Buildings, Railroads
80 BROAD STREET NEW YORK

SANDERSON & PORTER
ENGINEERS
FINANCING—REORGANIZATION—DESIGN—CONSTRUCTION of INDUSTRIALS and PUBLIC UTILITIES
Chicago New York San Francisco

J. W. OPAT
Consulting Engineer
TELEPHONE ENGINEERING
Construction Supervision
Appraisals—Financial
Rate Investigations
303 East Berry St. Fort Wayne, Indiana

SARGENT & LUNDY
Incorporated
ENGINEERS
140 South Dearborn Street
CHICAGO, ILLINOIS

J. G. WRAY & CO.
Engineers
Utilities and Industrial Properties
Appraisals Construction Rate Surveys
Plans Organizations Estimates
Financial Investigations Management
105 West Adams St., Chicago

WHEN YOU
require technical advice—or
a solution to an engineering problem—
CONSULT THIS DIRECTORY

Employment Bulletin

Engineering Societies Employment Service

MAINTAINED for their members by the national societies of civil, mining, mechanical, and electrical engineers, in co-operation with other organizations. An inquiry to any of the three offices will bring full information.

A weekly bulletin of engineering positions open is available to members of the co-operating societies at a subscription of $3 per quarter or $10 per annum, payable in advance.

It is the interest of effective service, it is essential that members using the employment service keep the bureau office serving them advised at reasonable intervals concerning their availability for employment, concerning any change in status, and immediately upon acceptance of any employment.

Employers interested in the following announcements should address replies to the key numbers indicated, and mail to the New York office.

Men Available

ENGR OR SUPT, B.S.E.E., 34, married; elec constr; overhead, underground lines; R.R. electrification; bldgs; Penna State license; available immed; go anywhere; prefers East or West Coast. E-307.

ELEC ENGR, 23 yrs exper in all phases of elec util work. Wide exper in dist des including the devpmt of A.C. networks. Minimum salary $6,000. E-3090.

GRAD E.E., 30, married. Exec ability; 5 yrs gen des and supervision elec constr; 1½ yrs traffic mgr and expediter; 1½ yrs buyer elec material. Location, East. E-304.

E.E., married, 48; 19 yrs planning instal, elec service, tel pwr plants and office bldgs; 2 yrs supervision elec constr. E-305.

ELEC ENGR, Union College, '16, Sigma XI, 44; 22 yrs broad engg exper and unusually fine record in des and constr of pwr plants, substations, indus projects. Most recent work $6,000,000 pwr plant. E-311.

CHEM AND ELEC GRAD M.I.T.; 20 yrs indus-exper—research, quality control, prod, sales engg, mgmt, with emphasis on chem and electrochem devpmt from lab to mfg stage. E-316.

B.E.E., '38, Pratt Inst, age 23, desires pos with elec mfr, constr or pwr co. Location, East or Middlewest. E-302.

E.E.B.S., '37, Johns Hopkins, single, 21; 9 mos elec constr; 8 mos instrument draftg. Desires training pos leading to sales engg. Location immaterial. E-306.

B.S.E.E., recent grad night sch, single, 27; desires pos with advancement; at present employed. Salary, secondary to permanent pos. E-308.

B.S.E.E., Duke Univ, '38; 1 yr research in indus controler des, operation, application and maintenance. Desires pos with controller co. Location immaterial. E-310.

GRAD B.E.E., City Col of NY, 1938, single, 22; exper in radio service work. Desires pos as E.E. in com or electronic field. Location immaterial; salary secondary. Available immed. E-313.

B.E.E., Jan '38, 22; practical and theoretical training in elec engg and draftg. Pos desired in any engg draftg or testg capacity. Fluent Polish, 5 yrs German. Location, East preferred. E-314.

E.E., B.S., Univ of Ill, '38, 22, single, desires pos in elec engg field, preferably pub util or elec mfg. co. Location immaterial, available immed. E-315-9670-Chicago.

B.S.E.E., '36, single, 25; 2 yrs exper with Bell Tel System in eqpt maintenance, outside plant constr. Desires affiliation with util offering opportunity for advancement. Location, East. E-317.

E.E., B.S., 1932, Marquette Univ; 5½ yrs testg and des on small and medium sized indus A-C, D-C motors and generators. Single, 29. Desires sales engg pos. Available immed. Location immaterial. E-318.

TEACHER math, physics or elec engg, or com engr. Available immed. B.S.E.E., A.M.E.E., passed preliminary exam for Ph.D.; 20 yrs varied Bell Tel system and teaching exper. E-312.

Sc.B.E.E., Brown, '34, married, 27; 2½ yrs textile finishing plant engg. G.E. test, turbines, M. & G., indus contr. transm. E-303.

ENGINEERING SOCIETIES EMPLOYMENT SERVICE

NEW YORK	SAN FRANCISCO	CHICAGO
31 W. 39th St	57 Post St.	211 W. Wacker Dr.

Perfect INSULATING COMPOUNDS for a wide range of temperature

Cable Joint and Pothead Compounds with service records of many years standing. They show all the physical and electrical characteristics necessary for insulating materials of this class.

• WRITE FOR BULLETIN 186 •

MINERALLAC ELECTRIC CO.
25 NORTH PEORIA ST. CHICAGO

COPPERWELD

COPPER THICKNESS

–and what it means to you

THE copper thickness on Copperweld wire is accurately measured and guaranteed. It must be not less than 12½ per cent of the wire radius of 40 per cent conductivity wire, and not less than 10 per cent of the wire radius of 30 per cent conductivity wire.

That means long life, freedom from rusting and lowered maintenance costs, when you use Copperweld wire or strand for guys, messenger cable, overhead ground wire, telephone wire, signal line wire, rail bonds, fence, etc.

It means that Copperweld can be clamped, bent, served, twisted or spliced without injury to the thick protective covering of welded-on copper.

You can have all the advantages of Copperweld's guaranteed copper thickness and permanent high strength for surprisingly little. Seldom does the use of Copperweld add more than a few per cent to the total cost of the job.

You are invited to write for a copy of Specification BW35, which includes complete specifications and guarantee.

COPPERWELD STEEL COMPANY
Glassport, Pa.
COPPER · BRONZE · COPPERWELD · RODS, WIRE, AND STRAND

Science Abstracts

All electrical engineers actively engaged in the practice of their profession should subscribe to "Science Abstracts."

Published monthly by the Institution of Electrical Engineers, London, in association with the Physical Society of London, and with the cooperation of the American Institute of Electrical Engineers, the American Physical Society and the American Electrochemical Society, they constitute an invaluable reference library.

Through "Science Abstracts" engineers are enabled to keep in touch with engineering progress throughout the world, as one hundred and sixty publications, in various languages, are regularly searched and abstracted. "Science Abstracts" are published in two sections, as follows:

"A"—PHYSICS—deals with electricity, magnetism, light, heat, sound, astronomy, chemical physics.

"B"—ELECTRICAL ENGINEERING—deals with electrical plant, power transmission, traction, lighting, telegraphy, telephony, wireless telegraphy, prime movers, engineering materials, electrochemistry.

Through special arrangement, members of the A.I.E.E. may subscribe to "Science Abstracts" at the reduced rate of $5.00 for each section, and $10.00 for both. Rates to non-members are $9.00 for each section and $15.00 for both. Subscriptions should start with the January issue. The first volume was issued in 1898. Back numbers are available, and further information regarding these can be obtained upon application to P. F. Rowell, Secy., I.E.E., Savoy Place, Victoria Embankment, London, W. C. 2, England.

American Institute of Electrical Engineers
33 West 39th Street, New York

Advertised Products Index

AMMETER COMPENSATING COILS
Minerallac Electric Co., Chicago
AMMETERS VOLTMETERS
(See INSTRUMENTS, ELECTRICAL)
BATTERY CHARGING APPARATUS
General Electric Co., Schenectady, N. Y.
Westinghouse E. & M. Co., E. Pittsburgh
BUS BAR SUPPORTS
Burndy Engg. Co., Inc., New York
General Electric Co., Schenectady, N. Y.
CABLE ACCESSORIES
Anaconda Wire & Cable Co., New York
Burndy Engg. Co., Inc., New York
General Electric Co., Schenectady, N. Y.
Minerallac Electric Co., Chicago
CAPACITORS
Aerovox Corp., Brooklyn, N. Y.
General Electric Co., Schenectady, N. Y.
Westinghouse E. & M. Co., E. Pittsburgh
CIRCUIT BREAKERS
Air-Enclosed
General Electric Co., Schenectady, N. Y.
I-T-E Circuit Breaker Co., Philadelphia
Roller-Smith Co., New York
Westinghouse E. & M. Co., E. Pittsburgh
Oil
Allis-Chalmers Mfg. Co., Milwaukee
General Electric Co., Schenectady, N. Y.
Roller-Smith Co., New York
Westinghouse E. & M. Co., E. Pittsburgh
CLAMPS, GUY & CABLE
Malleable Iron Fittings Co., Branford, Conn.
CONDENSERS, ELECTROSTATIC
Aerovox Corp., Brooklyn, N. Y.
General Electric Co., Schenectady, N. Y.
General Radio Co., Cambridge, Mass.
Westinghouse E. & M. Co., E. Pittsburgh
CONDUIT PRODUCTS
General Electric Co., Bridgeport, Conn.
CONNECTORS, SOLDERLESS
Burndy Engg. Co., Inc., New York
General Electric Co., Schenectady, N. Y.
CONTROLLERS
Allis-Chalmers Mfg. Co., Milwaukee
General Electric Co., Schenectady, N. Y.
Rowan Controller Co., Baltimore, Md.
Westinghouse E. & M. Co., E. Pittsburgh
CONVERTERS, SYNCHRONOUS
Allis-Chalmers Mfg. Co., Milwaukee
General Electric Co., Schenectady, N. Y.
Westinghouse E. & M. Co., E. Pittsburgh
DYNAMOS
(See GENERATORS AND MOTORS)
ELECTRONIC TUBES
General Electric Co., Schenectady, N. Y.
Westinghouse E. & M. Co., E. Pittsburgh
GENERATORS AND MOTORS
Allis-Chalmers Mfg. Co., Milwaukee
General Electric Co., Schenectady, N. Y.
Westinghouse E. & M. Co., E. Pittsburgh
GROUND RODS
Anaconda Wire & Cable Co., New York
Copperweld Steel Co., Glassport, Pa.
INSTRUMENTS, ELECTRICAL
Graphic
Ferranti Electric, Inc., New York
General Electric Co., Schenectady, N. Y.
Reeds & Northrup Co., Philadelphia
Roller-Smith Co., New York
Westinghouse E. & M. Co., E. Pittsburgh
Weston Elec. Instrument Corp., Newark, N. J.
Indicating
Ferranti Electric Inc., New York
General Electric Co., Schenectady, N. Y.
G-M Laboratories, Inc., Chicago
Leeds & Northrup Co., Philadelphia
Roller-Smith Co., New York
Westinghouse E. & M. Co., E. Pittsburgh
Weston Elec. Instrument Corp., Newark, N. J.
Integrating
Ferranti Electric, Inc., New York
General Electric Co., Schenectady, N. Y.
G-M Laboratories, Inc., Chicago
Westinghouse E. & M. Co., E. Pittsburgh
Weston Elec. Instrument Corp., Newark, N. J.
Scientific, Laboratory, Testing
Acme Elec. & Mfg. Co., Cuba, N. Y.
Ferranti Electric, Inc., New York
General Electric Co., Schenectady, N. Y.
General Radio Co., Cambridge, Mass.
Leeds & Northrup Co., Philadelphia
Roller-Smith Co., New York
Westinghouse E. & M. Co., E. Pittsburgh
Weston Elec. Instrument Corp., Newark, N. J.
INSULATING MATERIALS
Cloth
General Electric Co., Bridgeport, Conn.
Minerallac Electric Co., Chicago
Westinghouse E. & M. Co., E. Pittsburgh
Compounds
General Electric Co., Bridgeport, Conn.
Minerallac Electric Co., Chicago
Roebling's Sons Co., John A., Trenton, N.J.
Westinghouse E. & M. Co., E. Pittsburgh

INSULATING MATERIALS (cont'd)
Moulded
Bakelite Corp., New York
General Electric Co., Bridgeport, Conn.
Westinghouse E. & M. Co., E. Pittsburgh
Paper
General Electric Co., Bridgeport, Conn.
Insulation Manufacturers Corp., Chicago
Tape, Friction
Minerallac Electric Co., Chicago
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.
Westinghouse E. & M. Co., E. Pittsburgh
Varnishes
Bakelite Corp., New York
General Electric Co., Bridgeport, Conn.
Minerallac Electric Co., Chicago
Westinghouse E. & M. Co., E. Pittsburgh
INSULATORS, PORCELAIN
General Electric Co., Schenectady, N. Y.
Ohio Brass Co., Mansfield, O.
Westinghouse E. & M. Co., E. Pittsburgh
LIGHTNING ARRESTERS
General Electric Co., Schenectady, N. Y.
Westinghouse E. & M. Co., E. Pittsburgh
LOAD RECORDERS—CONTROLLERS
Leeds & Northrup Co., Philadelphia
LOCOMOTIVES, ELECTRIC
Allis-Chalmers Mfg. Co., Milwaukee
General Electric Co., Schenectady, N. Y.
Westinghouse E. & M. Co., E. Pittsburgh
METERS, ELECTRICAL
(See INSTRUMENTS, ELECTRICAL)
MOTORS
(See GENERATORS AND MOTORS)
POLE LINE HARDWARE
Malleable Iron Fittings Co., Branford, Conn.
Ohio Brass Co., Mansfield, O.
POLE MOUNTS
Malleable Iron Fittings Co., Branford, Conn.
RECTIFIERS
Allis-Chalmers Mfg. Co., Milwaukee
General Electric Co., Schenectady, N. Y.
Westinghouse E. & M. Co., E. Pittsburgh
REGULATORS, VOLTAGE
Allis-Chalmers Mfg. Co., Milwaukee
General Electric Co., Schenectady, N. Y.
General Radio Co., Cambridge, Mass.
Roller-Smith Co., New York
Westinghouse E. & M. Co., E. Pittsburgh
RELAYS
Dunn, Inc., Struthers, Philadelphia
General Electric Co., Schenectady, N. Y.
G-M Laboratories, Inc., Chicago
I-T-E Circuit Breaker Co., Philadelphia
Roller-Smith Co., New York
Westinghouse E. & M. Co., E. Pittsburgh
Weston Elec. Instrument Corp., Newark, N. J.
RESISTORS
Aerovox Corp., Brooklyn, N. Y.
Dunn, Inc., Struthers, Philadelphia
General Radio Co., Cambridge, Mass.
G-M Laboratories, Inc., Chicago
Ohmite Mfg. Co., Chicago
Westinghouse E. & M. Co., E. Pittsburgh
RHEOSTATS, LABORATORY
General Electric Co., Schenectady, N. Y.
G-M Laboratories, Inc., Chicago
Ohmite Mfg. Co., Chicago
Westinghouse E. & M. Co., E. Pittsburgh
SHEETS, ELECTRICAL
Carnegie-Illinois Steel Corp., Pittsburgh
SUB-STATIONS
Allis-Chalmers Mfg. Co., Milwaukee
General Electric Co., Schenectady, N. Y.
SURGE ABSORBERS
Ferranti Electric, Inc., New York
SWITCHBOARDS
Allis-Chalmers Mfg. Co., Milwaukee
General Electric Co., Schenectady, N. Y.
I-T-E Circuit Breaker Co., Philadelphia
Roller-Smith Co., New York
Westinghouse E. & M. Co., E. Pittsburgh
SWITCHES, AUTOMATIC TIME
General Electric Co., Schenectady, N. Y.
Minerallac Electric Co., Chicago
SWITCHES, DISCONNECT
General Electric Co., Schenectady, N. Y.
Roller-Smith Co., New York
Westinghouse E. & M. Co., E. Pittsburgh
SWITCHES GENERATOR FIELD
I-T-E Circuit Breaker Co., Philadelphia
TOWERS, TRANSMISSION
American Bridge Co., Pittsburgh
TRANSFORMERS
Acme Elec. & Mfg. Co., Cuba, N. Y.
Allis-Chalmers Mfg. Co., Milwaukee
Ferranti Electric, Inc., New York
General Electric Co., Schenectady, N. Y.
General Radio Co., Cambridge, Mass.
Westinghouse E. & M. Co., E. Pittsburgh
TURBINE GENERATORS
Allis-Chalmers Mfg. Co., Milwaukee
General Electric Co., Schenectady, N. Y.
Westinghouse E. & M. Co., E. Pittsburgh
TURBINES
Allis-Chalmers Mfg. Co., Milwaukee
General Electric Co., Schenectady, N. Y.
Westinghouse E. & M. Co., E. Pittsburgh
WATCHES, STOP
Meylan, A. R. & J. E., New York
WELDERS, ARC
General Electric Co., Schenectady, N. Y.
Westinghouse E. & M. Co., E. Pittsburgh
WELDING WIRE
American Steel & Wire Co., Chicago
General Electric Co., Schenectady, N. Y.
Roebling's Sons Co., John A., Trenton, N. J.
WIRES AND CABLES
Aluminum
Aluminum Co. of America, Pittsburgh
Armored Cable
American Steel & Wire Co., Chicago
Anaconda Wire & Cable Co., New York
Crescent Ins. Wire & Cable Co., Trenton, N. J.
General Cable Corp., New York
General Electric Co., Schenectady, N. Y.
Kerite Ins. Wire & Cable Co., New York
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.
Asbestos Covered
American Steel & Wire Co., Chicago
Anaconda Wire & Cable Co., New York
General Cable Corp., New York
General Electric Co., Bridgeport, Conn.
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.
Bare Copper
American Steel & Wire Co., Chicago
Anaconda Wire & Cable Co., New York
Copperweld Steel Co., Glassport, Pa.
Crescent Ins. Wire & Cable Co., Trenton, N. J.
General Cable Corp., New York
Roebling's Sons Co., John A., Trenton, N. J.
Bronze
Copperweld Steel Co., Glassport, Pa.
Copper Covered Steel
American Steel & Wire Co., Chicago
Anaconda Wire & Cable Co., New York
Copperweld Steel Co., Glassport, Pa.
General Cable Corp., New York
Flexible Cord
American Steel & Wire Co., Chicago
Anaconda Wire & Cable Co., New York
Crescent Ins. Wire & Cable Co., Trenton, N. J.
General Cable Corp., New York
General Electric Co., Schenectady, N. Y.
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.
Heavy Duty Cord
American Steel & Wire Co., Chicago
Anaconda Wire & Cable Co., New York
Crescent Ins. Wire & Cable Co., Trenton, N. J.
General Cable Corp., New York
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.
Lead Covered (Paper and Var. Cambric Ins.)
American Steel & Wire Co., Chicago
Anaconda Wire & Cable Co., New York
Crescent Ins. Wire & Cable Co., Trenton, N. J.
General Cable Corp., New York
General Electric Co., Schenectady, N. Y.
Kerite Ins. Wire & Cable Co., New York
Okonite Company, The, Passaic, N. J.
Okonite-Callender Cable Co., Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.
Magnet
American Steel & Wire Co., Chicago
Anaconda Wire & Cable Co., New York
Crescent Ins. Wire & Cable Co., Trenton, N. J.
General Cable Corp., New York
General Electric Co., Schenectady, N. Y.
Roebling's Sons Co., John A., Trenton, N. J.
Rubber Insulated
American Steel & Wire Co., Chicago
Anaconda Wire & Cable Co., New York
Crescent Ins. Wire & Cable Co., Trenton, N. J.
General Cable Corp., New York
General Electric Co., Schenectady, N. Y.
Kerite Ins. Wire & Cable Co., New York
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.
Tree Wire
American Steel & Wire Co., Chicago
Anaconda Wire & Cable Co., New York
Crescent Ins. Wire & Cable Co., Trenton, N. J.
General Cable Corp., New York
Kerite Ins. Wire & Cable Co., New York
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.
Weatherproof
American Steel & Wire Co., Chicago
Anaconda Wire & Cable Co., New York
Crescent Ins. Wire & Cable Co., Trenton, N. J.
Copperweld Steel Co., Glassport, Pa.
General Cable Corp., New York
General Electric Co., Schenectady, N. Y.
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.

BEHIND YOUR GOOD TELEPHONE SERVICE IS THE

Constant Courtesy OF

THE VOICE WITH A SMILE

THE MAN ON THE JOB

THE MEN AND WOMEN IN THE TELEPHONE OFFICE

This country is entitled, in good times and bad, to the best possible telephone service at the lowest possible price. A great factor in accomplishing this is the real spirit of service that has become a tradition among telephone men and women. Courtesy and efficiency are important words in the Bell System.

BELL TELEPHONE SYSTEM

Still Serviceable After Fourteen Years

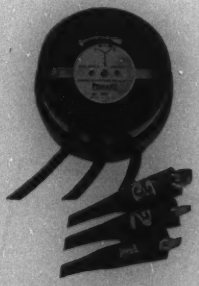
In 1924 this chestnut pole required replacement or salvage because of ground-line decay. The Williams Pole Mount salvage method was employed. Today the pole appears sound enough for another 14-year period. Equivalent Williams Pole Mount construction now would cost from $38.00 to $40.00 for grouped jobs to about $45.00 for single poles—with some extras for freight beyond 200 miles and for transportation to relatively inaccessible pole locations.

Spreading this salvage cost over the demonstrated life gives annual maintenance cost of about $3.00 to date, reducible to about $1.50 by extending the useful life to 1950. Then the Pole Mount unit on permanent concrete base is ready to receive replacement pole at same location at cost of perhaps $5.00 plus pole and overhead changes—or the entire unit may be salvaged for use elsewhere.

Figure against the above the cost of replacement of pole otherwise required in 1924 to carry trolley feeders, telephone and light and power services with riser pipe, and question whether that replacement would last until 1950. You then have the answer as to which method is cheaper. About 7,000 successful installations in United States and Canada prove we have an economic salvage construction device and method. Used also to support new poles to meet special anchorage conditions requiring development of full strength of pole.

INVESTIGATE
Send for M.I.F. Pole Hardware Specialties Catalog featuring also—Pole Stubbing Clamps—Cable Messenger Clamps—Rural Electrification Conductor Clamps—Insulated Hangers—Tubular Pole Fittings—Crossarm Gains—Through-bolt Guy Hooks and Accessory Eye Nuts, etc.

MALLEABLE IRON FITTINGS COMPANY
Pole Hardware Dept. [Factory and New England Sales Office] Branford, Connecticut
New York Sales Office: Thirty Church Street
Canadian Mfg. Distributors:
LINE & CABLE ACCESSORIES, Ltd., Toronto



Indispensable where metering equipment is involved in 3-phase supply.

FERRANTI PHASE ROTATION INDICATOR

The Ferranti Phase Rotation Indicator is provided with insulated clips numbered, 1, 2 and 3 which distinguish phase to which they should be attached. Direction of disc rotation tells immediately if phase rotation is correct. Invaluable also for correctly marking bus bars and leads.

Send for complete descriptive data

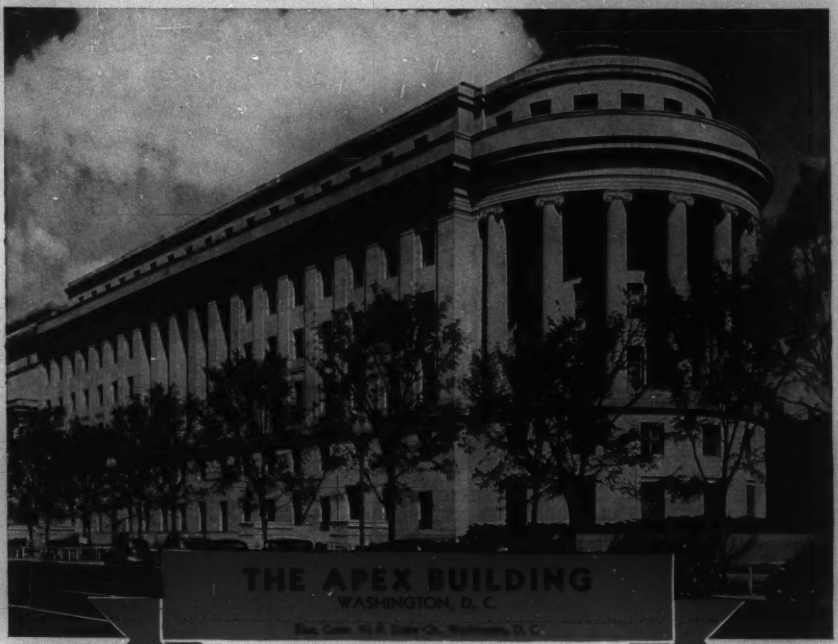
FERRANTI ELECTRIC, Inc. 30 Rockefeller Plaza New York, N. Y.

INDEX TO ADVERTISERS

	Page
Acme Electric & Mfg. Co.	12
Aerovox Corporation	13
Allis-Chalmers Mfg. Co.	2nd Cover
American Tel. & Tel. Co.	17
American Steel & Wire Co.	2
Black & Veatch	14
Copperweld Steel Co.	15
Crescent Ins. Wire & Cable Co. Inc.	3rd Cover
Engineering Directory	14
Engg. Soc. Employ. Service	12, 14
Engg. Soc. Library	12
Ferranti Electric, Inc.	1, 18
Fowle & Company, Frank F.	14
General Electric Co.	11
General Radio Co.	9
Industrial Notes	4
I-T-E Circuit Breaker Co.	5
Jackson & Moreland	14
Kerite Ins. Wire & Cable Co. Inc.	3
Malleable Iron Fittings Co.	18
Meylan, A. R. & J. E.	12
Minerallac Electric Co.	15
New Products	8
Ohmite Mfg. Co.	13
Okonite Company, The	4th Cover
Polachek, Z. H.	14
Roller-Smith Co.	13
Rowan Controller Co.	13
Sanderson & Porter	14
Sargent & Lundy, Inc.	14
Science Abstracts	15
Southgate, George T.	14
Standards of AIEE	10
United States Rubber Products, Inc.	6, 7
United States Steel Corp. Subsidiary	2
Warren, Howard S.	14
White Engg. Corp., The J. G.	14
Wopat, J. W.	14
Wray & Co., J. G.	14

VARNISHED CAMBRIC • RUBBER POWER CABLES • BUILDING WIRE • RADIO WIRES • SIGNAL CABLE • FLEXIBLE CORDS • LEAD-ENCASED AND PARKWAY CABLES • ARMORED CABLES

CRESFLEX NON-METALLIC SHEATHED CABLE • SERVICE ENTRANCE CABLE • MAGNET WIRE • BARE WIRE



WIRED THROUGHOUT WITH

CRESCENT ENDURITE

SUPER-AGING — HEAT RESISTING

INSULATED WIRE and CABLE

The completion of the Apex Building, housing the Federal Trade Commission, culminates a 10 year building program that has given Washington, D. C. its famed Federal Triangle. Built to last for generations, the Apex Building is wired for permanence from cellar to roof with CRESCENT ENDURITE Insulated Wire and Cable.

CRESCENT ENDURITE is the logical choice where conductors are subject to excessive temperature and aging conditions; where maximum life is of prime importance and cost of replacement is prohibitive.

CRESCENT
INSULATED WIRE & CABLE CO. INC.
TRENTON, NEW JERSEY

CRESCENT ENDURITE SUPER-AGING INSULATION • WEATHER-PROOF WIRE

OKOLITE

Resistant to HEAT·MOISTURE·CORONA

A dramatic picture but it shows the destructive processes going on in rubber-insulated cables when an unsuitable insulation is subjected to corona and extremes of temperature and moisture.

Okolite insulation handles these conditions. It is effectively resistant to heat, moisture and corona. Where it is desired to avoid having a lead sheath, Okolite is the satisfactory insulation.

Okolite insulation meets exacting laboratory tests and is backed with an impressive performance record. Millions of feet of Okolite insulated cable are operating in diversified use throughout the country.

Okolite insulation can effect large savings in plant construction and maintenance. A study of Okolite characteristics and performance will show the wide usefulness of this insulation. Its scope ranges from a small control cable to heavy generator leads —or a submarine power cable.

1938 Marks Our 60th Year of Service

OKONITE

THE OKONITE COMPANY

Founded 1878

EXECUTIVE OFFICE: PASSAIC, NEW JERSEY

HAZARD INSULATED WIRE WORKS DIVISION

THE OKONITE-CALLENDER CABLE CO., INC.

New York Boston Seattle Buffalo Chicago Dallas Detroit Atlanta

Philadelphia Los Angeles Pittsburgh St. Louis Washington San Francisco

OKONITE QUALITY CANNOT BE WRITTEN INTO A SPECIFICATIO